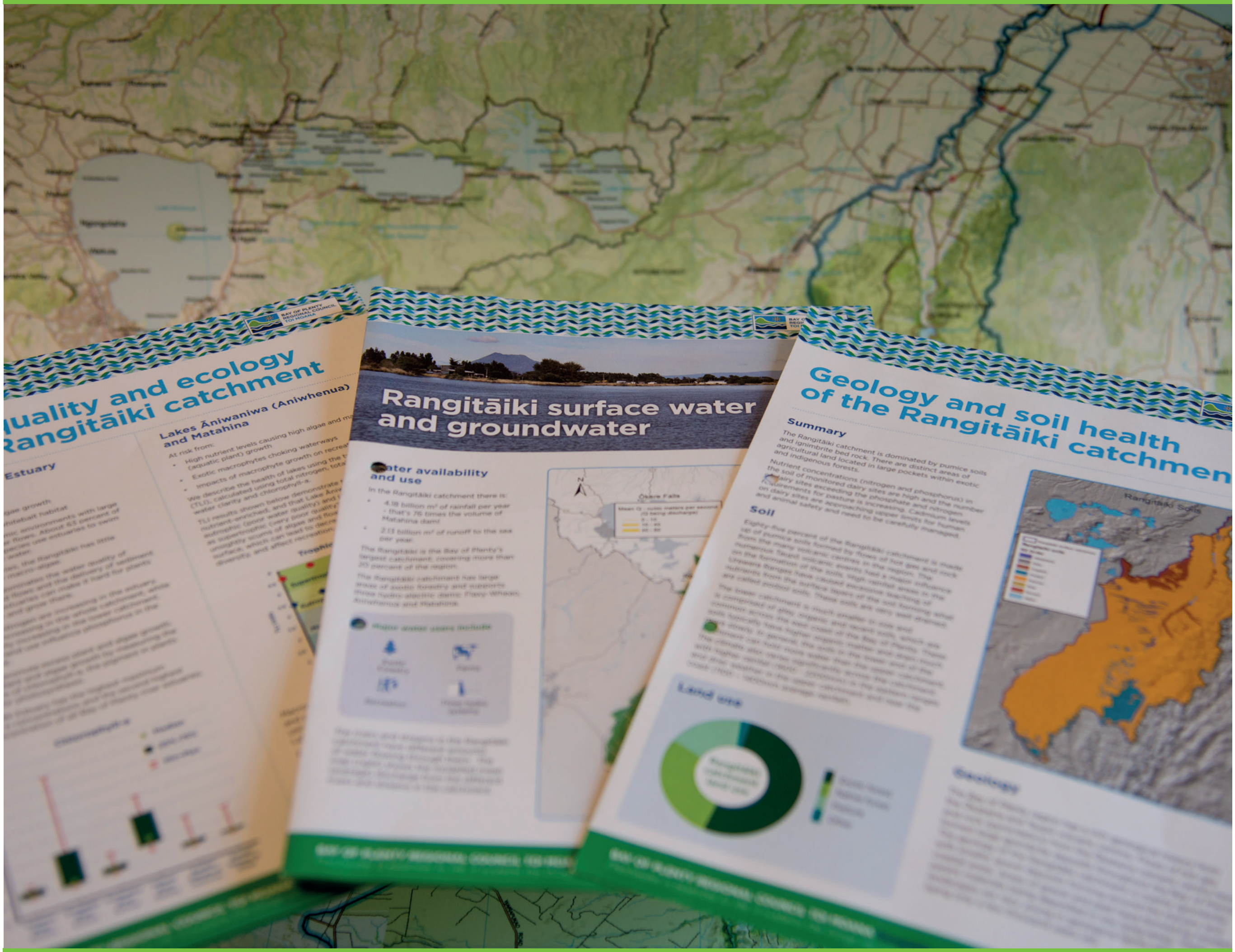
Rangitāiki Water Management Area: Current State and Gap Analysis



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Whakatāne 3158
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Prepared by Rochelle Carter (Water Quality Scientist), Alastair Suren (Freshwater Ecologist), Raoul Fernandes (Hydrologist), Marcus Bloor (Soil Scientist) Janine Barber (Senior Groundwater Scientist), Shay Dean (Wetland Ecologist)

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1	Paul Scholes	Rob Donald	8 March 2016
2	Rob Donald		
3	Ned Norton/ Ton Snelder (Land Water People)*		
4	Nicola Green		
5	Rob Donald		

* The report titled ‘Kaituna Water Management Area: Current State and Gap Analysis (Environmental Publication 2016/01)” was reviewed by Land Water People. Comments made by reviewers were applied to this report where applicable.

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Executive summary

1 The National Policy Statement for Freshwater Management 2014 (NPS-FW) directs Council to manage fresh water in an integrated and sustainable way, within water quality and quantity limits. Limits relate to the values and objectives for which a water body, or part of a water body, is being managed.

2 Bay of Plenty Regional Council (BOPRC) needs to provide information on the current state of waterways in the region, as well as information on the pressures responsible for this current state. It is expected that the Council will work with communities to establish freshwater objectives (i.e. desired states) for water quantity and water quality throughout the region, and set limits on resource use which allow those objectives to be met.

3 BOPRC is implementing the NPS-FW progressively by working in priority catchments (called Water Management Areas) first, of which the Rangitāiki is one. This report provides a summary stocktake of all science work conducted in the Rangitāiki WMA (especially that relevant to compulsory national attributes), firstly to identify our current state of knowledge, and secondly to identify what knowledge gaps are apparent. The report has the following aims:

(a) to describe the spatial extent of different waterway types throughout the Rangitāiki WMA when classified according to the River Environment Classification (REC),

(b) to summarise the current surface water quality and quantity, and ecological monitoring programmes occurring in the Rangitāiki WMA, and to assess whether these represent the necessary different water body types,

(c) to summarise what current monitoring information does and does not tell us about the current state of freshwater (quality and quantity in particular),

(d) to summarise the land use and soil health, and groundwater monitoring programmes occurring in the Rangitāiki WMA,

(e) to identify gaps in monitoring programmes and strengthen linkages between monitoring programmes in the Rangitāiki WMA, and

(f) to make recommendations for future work to be undertaken to help fill the identified knowledge gaps.

Note that full technical reports on science and information supporting any plan changes that are considered necessary, including what is and is not known about current state and trends, will be prepared at a later date.

4 Major science work programmes conducted in the Rangitāiki WMA include water quality, ecology (mainly invertebrates and fish), hydrology, soils and groundwater. Each of these science programmes was examined and reviewed with the aim of summarising the current condition, identifying gaps, and making recommendations. Information summarising the current condition came from a number of sources including the BOPRC library, the Natural Environment Regional Monitoring Network (NERMN) programme, consent and compliance monitoring investigations, and other studies that have been undertaken throughout the Rangitāiki WMA.

5 This review of current state allowed the identification of knowledge gaps in the different monitoring programmes, which led to a number of recommendations being made. All recommendations were subsequently assigned to one of six themes:

(a) Spatial frameworks

(b) Obtain new data

(c) Improvements to methods and reporting

(d) Identify values

(e) Data for models

(f) Data management.

As some of the recommendations in this report are compiled from existing reports, each recommendation has been given a ‘Status’ to indicate whether the recommendation is ‘New’, ‘Already Underway’, or ‘Planned and Resourced’. Some recommendations (e.g. periphyton monitoring) were identified in previous reviews and have been allocated resources, and some are currently being implemented. These existing recommendations have been included in this report for completeness.

6 The importance of creating a consistent and relevant spatial framework for implementation of the NPS-FW was identified across all science work programmes. It is considered impractical to describe the current environmental state, identify freshwater objectives, and set and implement numerical limits for water quality and quantity at the WMA level. There is simply too much natural variability between waterways in each WMA for this process to be workable. In recognition of this, the NPS-FW requires councils to create Freshwater Management Units (FMUs) that need to consider the importance of both stream hydrology and catchment conditions – both of which influence water quality and ecology. A key requirement of FMUs is, therefore, to group streams according to overarching environmental factors that constrain ecological and water quality conditions. These groups form part of a spatial classification of waterways, which will be used to identify their current ecological state, while ensuring that such comparisons are not compounded by natural differences between streams caused by climate, flow regime or geology. BOPRC thus needs to investigate which spatial frameworks are most appropriate.

7 With the exception of invertebrate and fish monitoring, all the science programmes examined identified the need to obtain new data from within the Rangitāiki WMA. This reflects the fact that the NPS-FM has placed greater requirements that were not previously known or foreseen. Thus many of the current monitoring programmes were set up to fulfil their own aims and purposes, and made efficient use of the limited resources available for monitoring. This has, however, left unintended consequences with a lack of monitoring from other areas that have now been identified as knowledge gaps from the perspective of implementing the NPS-FM requirements. For example, water quality and ecological monitoring is under-represented in hill fed rivers flowing through catchments dominated by exotic plantation forestry or native vegetation. While some of these knowledge gaps have been filled recently following a large-scale ecological survey throughout the catchment (Suren 2014), gaps still exist in other ecological and water quality monitoring programmes. The soil monitoring programme is also under-represented in catchments dominated by dairy farming. Other science gaps reflect a lack of information in emerging fields such as the interactions between ground and surface waters. Of all the themes identified in the recommendations, obtaining new data is likely to have the greatest cost implications.

8 The setting of water quality and quantity limits is central to the implementation of the NPS-FW. Limits are defined as “the maximum amount of resource use available, which allows a freshwater objective to be met”. Limits are thus needed for the amount of water that can be abstracted from a specific waterway without compromising its values, or need to be established as a maximum load of contaminants (e.g., bacteria or nutrients) that a catchment can accommodate without compromising values such as the need to maintain swimmable water, or the need to keep periphyton (slime) to levels below specific bands that are deemed unacceptable to the community. When considering limits, it is likely that computer models will be needed to examine relationships between, for example, land use and nutrient inputs into both surface and groundwater, and between water quantity in groundwater and surface waters. Such models would link key processes associated with the effects of land-use intensification, and would provide important feedback to the community and BOPRC as to the physical, chemical and biological implications of various land-use scenarios. Scenario testing is particularly important as it allows the social and economic consequences of different objectives to be examined transparently. Model development and testing are critical to such scenario testing, and is thus recommended for many science work programmes.

9 While not specifically a knowledge gap for the Rangitāiki WMA, the importance of good data management has been highlighted by this review. The lack of a centralised data repository for all water quality and ecological sampling has been identified, along with the difficulty of obtaining data from both the Council's NERMN programme, and from the numerous compliance or consent investigations that have been undertaken. Although centralised databases for some work programmes have been created (e.g. the use of Aquarius for all flow data, and the development of individual databases for invertebrate and fish data), future implementation of work programmes as part of the NPS-FW will greatly benefit from more streamlined database processes that maximise both discoverability and accessibility of data.

10 In conclusion, while this review shows that BOPRC monitors a wide range of parameters in the Rangitāiki WMA, it is apparent that there are many gaps in the current monitoring programmes. The challenge is how to best fill these gaps given the reality of constrained resources and time. The next step is to prioritise and rank these knowledge gaps so that the needs of the NPS-FW implementation process are met. In undertaking such a ranking process, it is important to consider a number of key issues, including that:

- monitoring needs to examine more than just the current compulsory national attributes,
- monitoring needs to be representative of the range of land uses,
- monitoring design needs to be aware of the often strong links (connectivity) between groundwater and surface water in streams, rivers, lakes and estuaries,
- there is a need for better integration of different science programmes, and
- there is a need to consider the data and information needed to support computer models.

11 By considering these issues as part of the gap analysis and prioritisation process, it is expected that more informed decisions can be made about gaps which need to be addressed as a matter of urgency and those which can be regarded as optional.

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Part 1: Overview

1.1 Purpose of this report

This report provides an overview of the current state of land and freshwater natural resources in the Rangitāiki Water Management Area (hereafter referred to as the Rangitāiki WMA) and identifies gaps in our scientific knowledge. This information is needed to support implementation of the National Policy Statement for Freshwater Management 2014 (the NPS-FW).

The report covers the ecological, hydrological, water quality, land and soil, and groundwater characteristics of the Rangitāiki WMA. While this work was restricted to the science areas listed above, Part 13 of this report outlines other considerations that were beyond the current scope of this report.

The report has the following aims:

(a) to describe the spatial extent of different waterway types throughout the Rangitāiki WMA when classified, according to the River Environment Classification (REC),

(b) to summarise the current surface water quality and quantity, and ecological monitoring programmes occurring in the Rangitāiki WMA, and to assess whether these effectively represent all of the different water body types,

(c) to summarise the land use and soil health, and groundwater monitoring programmes occurring in the Rangitāiki WMA,

(d) to summarise the current state of the wetland and estuary monitoring occurring in the Rangitāiki WMA,

(e) to identify gaps in monitoring programmes and strengthen linkages between monitoring programmes in the Rangitāiki WMA,

(f) to make recommendations for future work to be undertaken to help fill the identified knowledge gaps.

Note that full technical reports on science and information supporting any plan changes that are considered necessary, including what is and is not known about current state and trends, will be prepared at a later date.

1.2 The NPS for Freshwater Management

The National Policy Statement for Freshwater Management 2014 (NPS-FW) directs councils to manage fresh water in an integrated and sustainable way, within water quality and quantity limits. Limits relate to the values and objectives for which a water body, or part of a water body, is being managed. Of particular relevance to this report, the NPS-FW includes requirements to:

1 implement a National Objectives Framework for establishing freshwater objectives, which includes:

  (a) consideration of the current state of freshwater management units,

  (b) assigning a current state for specified national attributes and other attributes that Council considers appropriate (for compulsory and other appropriate values),

2 establish environmental flows and levels,

3 establish a monitoring plan to monitor progress towards, and achievement of, freshwater objectives, and

4 establish an accounting system for freshwater quality and quantity, including making required accounting available to the public.

These requirements are to be applied at a Freshwater Management Unit (FMU) scale. At the time this report was prepared BOPRC had already decided to divide the region into 9 Water Management Areas (WMAs), and to implement the NPS-FW in stages across 2-3 WMAs at a time, starting with the Rangitāiki WMA and the Kaituna WMA (see Figure 1). However, BOPRC had not identified FMUs, or values and attributes in addition to the compulsory national attributes set in the NPS-FW. These will all be the subject of separate reports. Hence this current state and gap analysis is an initial collation of what we know and monitor with a particular focus on deficiencies in our monitoring and data and recommendations for addressing these.

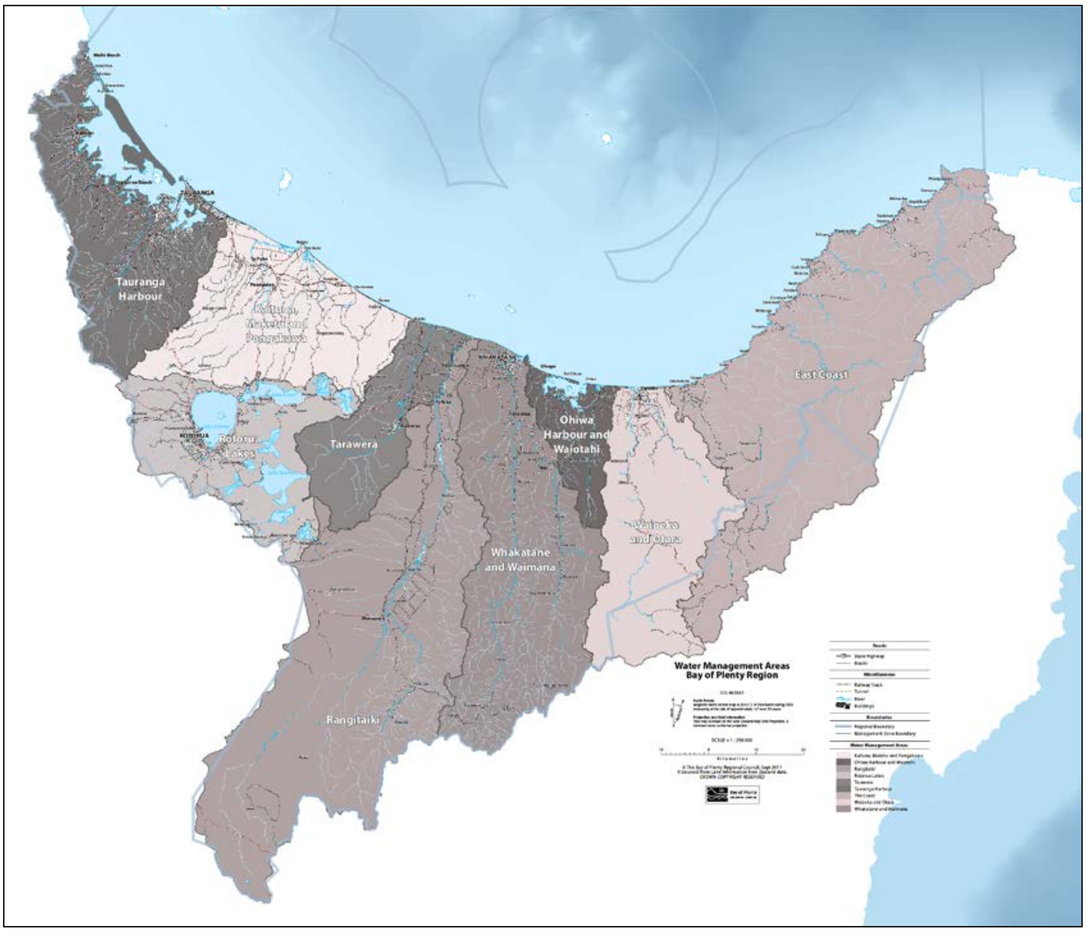


Figure 1 Map of the nine Water Management Areas in the Bay of Plenty region.

The NPS-FW sets national bottom lines for two compulsory values: ecosystem health and human health for recreation. It also currently specifies the following attributes to support the compulsory values and these define the National Objectives Framework (NOF):

- algae (periphyton) – lakes and rivers
- total nitrogen and total phosphorus - lakes
- nitrate (for toxicity) – rivers
- ammonia (toxicity) – lakes and rivers
- dissolved oxygen (below point source discharges) - rivers
- Escherichia coli (E. coli) – lakes and rivers
- Cyanobacteria – Planktonic – lakes and lake fed rivers

Four discrete state bands (A, B, C, and D) have been identified for each of these attributes, with the bottom of C band representing ‘national bottom lines’. Where waterways are below these bottom lines, they will need to be improved to at least the national bottom line over time.

Note that while this report specifically focusses on current state and trend information and monitoring for these compulsory national attributes, some additional parameters are also discussed (e.g. invertebrates). Further work will need to be carried out on identifying appropriate additional attributes to support values within the WMA and identifying current state and gaps for these.

The NPS-FW also requires council to establish environmental flows and levels to give effect to objectives set, and to amend regional plans to provide for the efficient allocation of fresh water to activities within the limits set to give effect to these. This current state report therefore also summarises the state of data we hold relating to surface and groundwater hydrology.

Following on from the review of physical and ecological monitoring programmes in the Rangitāiki WMA, a number of high-level issues such as the need to monitor a representative range of sites throughout the WMA, as well is the importance of linkages between different ecosystems is discussed (Part 13). The need for better integration of monitoring programmes and linking monitoring programmes to modelling is also discussed in this final part.

1.3 Review process

This review is based on an extensive literature review of all reports assembled on the Rangitāiki WMA from the BOPRC library, access to the current (NERMN) monitoring network data, as well as some external data sources. It also makes use of the River Environment Classification (REC) to give a spatial context to the previous studies.

Regional monitoring conducted by BOPRC as part of its NERMN programme is summarised in the report, as well as monitoring conducted by other organisations as part of either consent or compliance monitoring, where this was readily available. Based on these summaries, a number of knowledge gaps have been identified. Consequently, recommendations have been made to fill these knowledge gaps within the Rangitāiki WMA.

The NERMN programme was recently reviewed by Donald (2014), where a number of high-level recommendations were made. Such recommendations included expanding the number of monitoring sites to include areas currently under-represented in the monitoring programme (e.g., sampling in hill-country streams, streams dominated by non-volcanic geology, or streams draining catchments dominated by exotic or native forest), as well as alterations to sampling methodologies (e.g., increasing water quality sampling to monthly at all sites). Many of these recommendations are also applicable to monitoring within the Rangitāiki WMA. However, the intent of this report is to refine these more general recommendations of the regionally based NERMN Programme, to more specific recommendations based on the Rangitāiki WMA and knowledge gaps identified there.

Following the identification of recommendations within each science work stream, a prioritisation and ranking process will be required so that the most important recommendations that address knowledge gaps are implemented. For ease of prioritising, all recommendations were assigned to one of six themes:

(a) Spatial frameworks

(b) Obtain new data

(c) Improvements to methods and reporting

(d) Identify values

(e) Data for models

(f) Data management.

Implementation of selected recommendations will help ensure that any future monitoring work is conducted to fulfil the aims of both the NERMN programme, and Government policy such as the NPS-FW.

It should be noted that this summary has focussed only on chemical, biological and physical measures of waterway attributes as assessed using western scientific methods. It does not include other assessments of stream values associated with cultural values (and in particular those of iwi), recreational, landscape or economic values. All monitoring outlined in this report is based on western science and does not directly consider tangata whenua values and interests. However, we acknowledge that there needs to be opportunities for cultural health monitoring (or other appropriate measures of mauri) and inclusion of this information will greatly broaden our spectrum when helping communities to define the current state of a waterway, and assess its values. Due consideration should thus be given to these other values as part of implementation of the NPS-FW throughout the region.

1.4 Report structure

This report is written in 14 Parts and has been structured in a logical order that follows the hydrological cycle:

- **Part 1** explains the rationale behind the report and its links to the NPS-FW.
- **Part 2** explains the need to develop spatial classification of waterways.
- **Part 3** describes geology, land use and soils.
- **Parts 4 and 5** describe stream hydrology and groundwater.
- **Part 6** describes the water quality of rivers and streams.

- **Part 7** describes the water quality and ecology of the hydro lakes.
- **Parts 8, 9, 10 and 11** describe freshwater ecology (periphyton, cyanobacteria, macroinvertebrates and fish).
- **Part 12** describes wetlands.

The report concludes in **Parts 13 and 14** with other consideration and a summary of the recommendations that are provided throughout the report.

Part 2: Spatial classification

2.1 Introduction

Although BOPRC has decided to implement the NPS-FW in nine WMAs, it is important to emphasise that the actual limit setting process and community discussion on setting appropriate bands for the different compulsory national attributes needs to be made at spatial scales different to that of a WMA. Many of the attributes measured under the NOF vary in response to environmental factors such as climate, source of flow (where water comes from, e.g. lake fed streams or hill fed streams), geology and land use. These factors impose natural constraints on a waterway's inherent character, and therefore on the overall NOF banding of a river. For example, algal biomass is a product of both a stream's nutrient regime, and its flow regime. Thus algal biomass is unlikely to be high in a stream with high nutrients and a high flood frequency, but could conceivably be high in a stream with lower nutrients but a lower flood frequency.

Because of this, it is necessary for BOPRC to group streams according to overarching environmental factors that ultimately constrain ecological and water quality conditions. It is likely that these groups would form part of a spatial classification of waterways throughout the region which will be used to help set limits and identify desired states. These groups are equivalent to the Freshwater Management Units (FMUs) referred to in the NPS-FW. Once FMUs have been created, we can more accurately describe the current state of streams in each FMU.

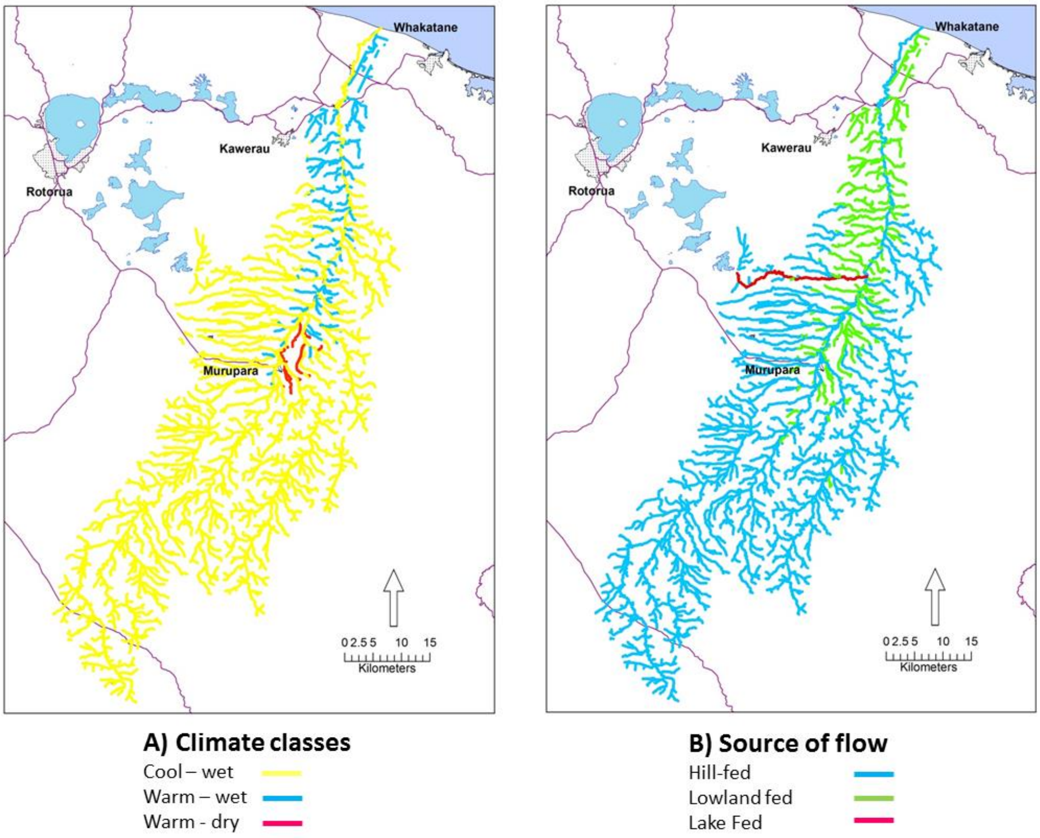
2.2 Spatial frameworks considered

A number of spatial classifications already exist, including the River Environment Classification (REC), and the Freshwater Environments of New Zealand (FENZ). The REC was developed by NIWA for MfE to provide a spatial framework for regional (or larger) scale environmental monitoring and reporting, environmental assessment and management (Snelder and Biggs 2002). It was developed to discriminate spatial variation in a wide range of stream characteristics, including physical and biological characteristics. It is a multi-scale classification, delineating patterns at a range of scales from approximately hundreds of km^2 to 1 km^2.

In the absence of any formal decision on what spatial framework should be used to create freshwater management units in the Bay of Plenty, we have used the REC to classify all waterways (rivers and streams) in the Rangitāiki WMA, according to parameters known to influence ecological communities such as climate, source of flow, geology and land cover (Figure 2). From this analysis, we were able to calculate the total length of waterways belonging to different REC classes, as well as the number of small, medium and large streams in the area. In this way a quantitative description of the waterways in the Rangitāiki WMA could be made to help inform the location of potential gaps in water quality, water quantity, soil or ecological monitoring programmes.

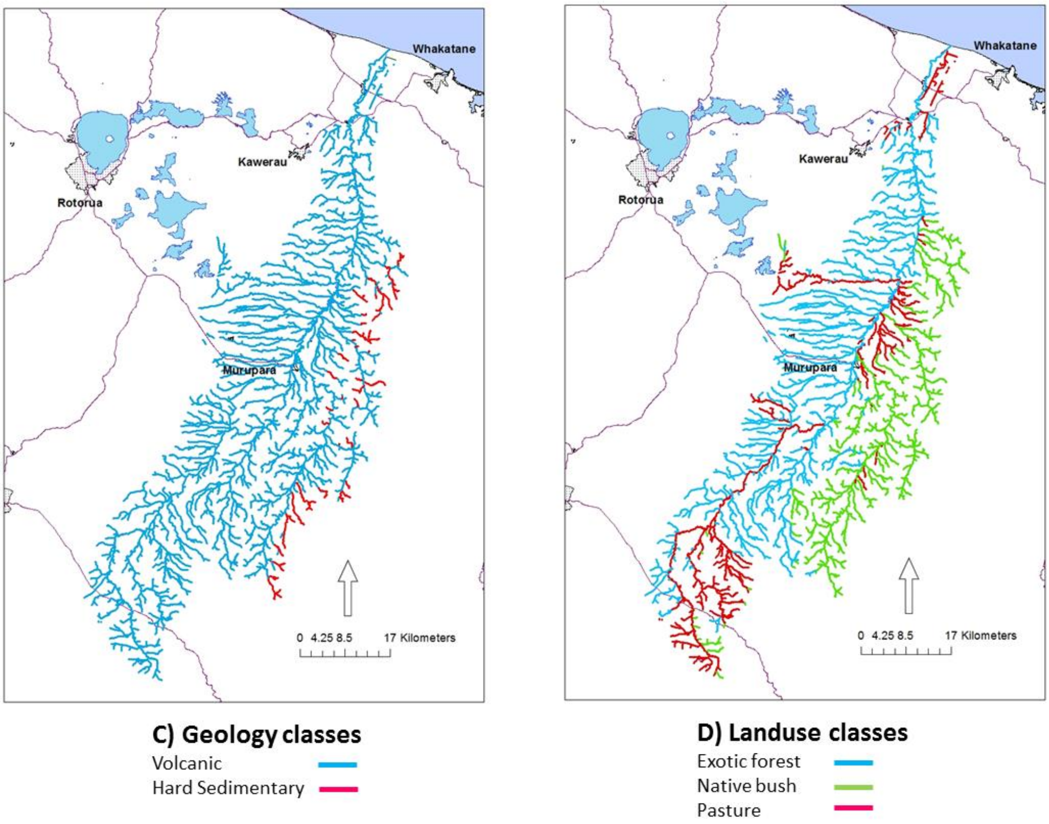
2.3 Results of the REC analysis for the Rangitāiki WMA

Suren (2014) provided a comprehensive assessment of the REC analysis of all waterways in the Rangitāiki Catchment. The information presented here is a snapshot of the information presented in Suren (2014). The REC analysis showed that approximately 4,400 km of waterways exist within the Rangitāiki WMA (Suren, 2014). Most of these (73%) were small first or second-order headwater streams, and large rivers (fifth order or greater) contributed only 6% of total waterway length (Table 1). The vast majority (~86%) of waterways were in the Cool-Wet climate class, while 12.7% were in the warm-wet class, and 1.5% in the warm-dry class. The dominant source of flow consisted of hill-fed streams (77.5%) and lowland-fed streams (21.6%, Table 1). Lake fed streams only occupied 0.7% of total stream length, and comprised the stream draining from Lake Rerewhakaaitu.



A) Climate classes

B) Source of flow



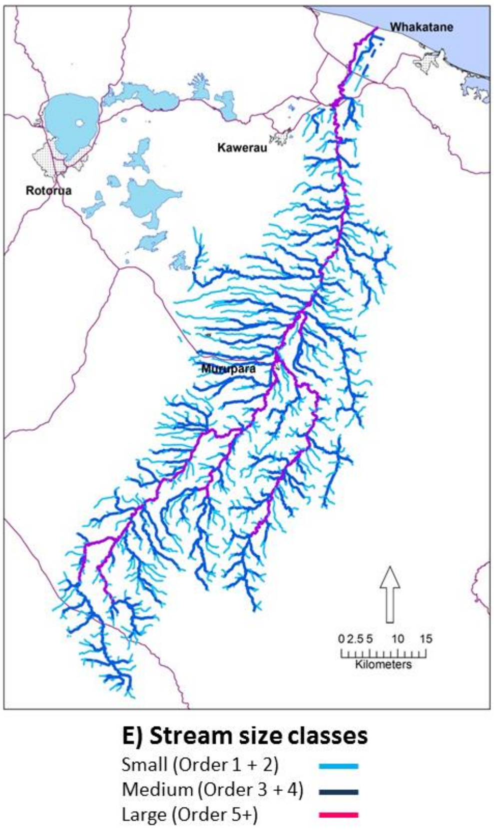


Figure 2 *Map of the Rangitāiki Catchment showing the location of waterways in different REC, A) climate, B) source of flow, C) geology, D) land use classes and E) stream size (Suren, 2014).*

The dominant geology consisted of volcanic material, which comprised 93.6% of stream length. Alluvium geological material composed 0.2% and there was only 0.1 km of miscellaneous geological material in the WMA. Approximately 21% of waterway length drained catchments classified as pastoral land use (representing either horticulture or grazing), while exotic forestry plantations were found in 50.9% of the waterway length. Natural vegetation (native forest, scrub and tussock) comprised 26.3% of the waterway length in the Rangitāiki WMA.

Note that this REC analysis considered only the percentage length of different waterways throughout the Rangitāiki WMA. An alternative analysis could be based on river flow and volume. For some attributes such as nutrient concentrations, water volume is important as it allows the calculation of catchment nutrient yields to be made. However, such calculations would be constrained by the fact that they would be based purely on modelled flows from each waterway, and could not consider the fact that these are highly temporally variable. Furthermore, reach length would be proportional to catchment area, and it is important to recognise that small streams have much higher segment-length to catchment area ratio than larger rivers. This means that small streams are in more intimate contact with the surrounding land use, and are arguably more sensitive to changes in land use condition than the larger rivers and streams.

Table 1 List of the different REC classes for climate, source of flow, geology, land cover and stream size found within the Rangitāiki WMA, showing the combined length of waterways in each class, as well as a percentage of waterway length.

Variable	Value	Stream length (km)	% of WMA stream length
Climate class	Cool-dry	4.86	0.1
	Cool-wet	3,771.41	85.7
	Warm-dry	64.85	1.5
	Warm-wet	560.91	12.7
Source of flow	Hill	3,412.44	77.5
	Lowland	950.30	21.6
	Lake	31.12	0.7
	Mountain	8.18	0.2
Geology	Alluvium	10.41	0.2
	Hard sedimentary	272.38	6.2
	Miscellaneous	0.10	0.0
	Volcanic acidic	4,119.15	93.6
Land cover	Exotic forestry	2,239.45	50.9
	Indigenous forestry	1,157.22	26.3
	Pastoral	920.89	20.9
	Scrub	43.66	1.0
	Tussock	36.12	0.8
	Urban	4.15	0.1
Stream size	Small (order 1+2)	3,216.31	73.1
	Medium (order 3+4)	920.71	20.9
	Large (order 5+)	265.01	6.0

The conclusion from this analysis is that the vast majority of waterways in the Rangitāiki WMA are represented by small streams, draining catchments dominated by volcanic geology and supporting predominantly exotic plantation forestry, followed by indigenous forestry and pastoral land use. Monitoring programmes need to ensure that these stream types are monitored according to their occurrence within the Rangitāiki WMA to be representative of dominant conditions within the Rangitāiki WMA.

2.4 Gaps and recommendations

Table 2 outlines the gaps identified and provides recommendations to fill the gaps.

Table 2 Identified gaps for spatial considerations and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Spatial framework	Under the NPS-FW, councils are expected to create Freshwater management units. These units need to represent streams which are similar to each other, so that appropriate limits for the compulsory national attributes can be accurately determined.	BOPRC needs to consider which spatial framework is appropriate to create freshwater management units. These units could be based on either the REC or FWENZ classifications, or an alternative. To assist with decision-making, it may be cost-effective to get input from external experts on this matter.
Spatial framework	Lack of spatial classification for all monitoring programmes.	Develop a consistent spatial classification for different monitoring programmes (e.g. water quality and quantity, land use and soils, and ecology).

Part 3: Geology, land use and soils

3.1 Introduction

Geology, land use and soils are important drivers influencing water quality and quantity. This section describes the geological setting in the Rangitāiki WMA, the current state in terms of land use and soils, and identifies information gaps for soil health and land use.

3.2 Geology

The Bay of Plenty region has been shaped by a rich history of geological activity, particularly from the Ōkataina and Taupō volcanic centres. Geology within the Rangitāiki Catchment is typical of the wider Bay of Plenty region with large areas of ignimbrite created by flow tephra events thousands of years ago (Molloy, 1998). On a geological timescale these landscapes are very young, some of which are only a few thousand years old (Molloy, 1998).

Numerous successive eruptions of tephra (volcanic air fall material) following as many as 12 eruptions in the past 40,000 years have been the driving force behind the geology and formation of soils in the region (Molloy, 1998).

The majority of the Rangitāiki WMA consists of ignimbrite formed by pyroclastic flows from previous eruptions (Figure 3). Significant greywacke sandstone areas underpin much of the eastern edge of the Rangitāiki WMA. These areas have not been impacted as significantly by the general north easterly flows of pyroclastic flows (Molloy, 1998).

3.3 Soil formation

The interactions among the principal factors of soil formation (parent material, climate, topography, vegetation and time) and soil-forming processes have given the soils of the Bay of Plenty their distinctive characters. Parent materials range from thick layers of volcanic ash mantling the surface, to alluvium derived from greywacke, sandstone, mudstone and volcanic ash, to peat and wind-blown sand.

Volcanic eruptions occurred at different times from sources in the Rotorua and Taupo Districts, depositing coarse volcanic material called lapilli and blocks over the Bay of Plenty. Finer material or ash was usually deposited during the final stages of an eruption at greater distances away from the volcanoes.

Climate is probably the most important factor influencing present-day land use within the Bay of Plenty. The climate varies from warm and moist in coastal areas to cool and moist in the uplands of Urewera National Park, the Mamaku Plateau and the Kaimai Range. It is probably the most important factor influencing present-day land use. The influence of topography is somewhat subdued in a landscape mantled by tephra; however, strong dissection of hill country and steep land country influences the layers of tephra remaining on the slopes, and induces erosion and deposition of material on valley floors.

The region is somewhat sheltered from prevailing winds by the high country of the North Island. Consequently, the Bay of Plenty has a sunny climate with dry spells, but may have prolonged heavy rainfall periods. Annual rainfall ranges from about 1,200 mm at the coast to over 2,000 mm inland at higher elevations, but decreases again in inland basins such as near Murupara.

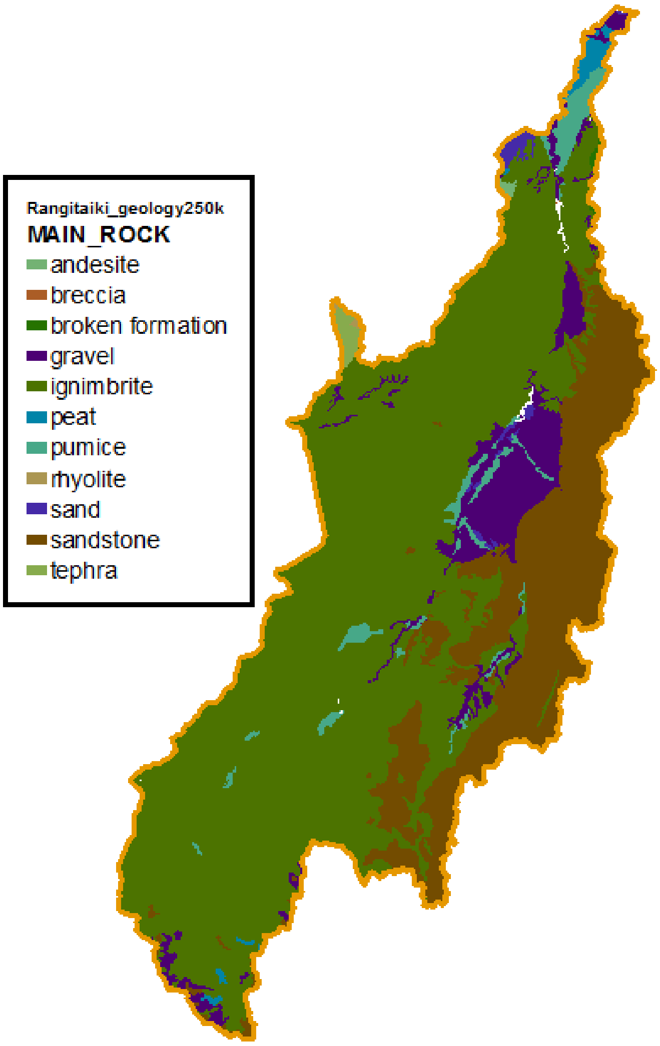


Figure 3 Geology within the Rangitāiki Catchment.

Rainfall plays an important part in the development of soils. Broadly speaking, the higher the rainfall the stronger the leaching that takes place in the soil and, at annual rainfall over 1,800 mm, podzolisation processes (the leaching of certain minerals from the A and E horizons) are evident in the subsoil (redder subsoil).

There is also a clearly defined winter rainfall maximum, with approximately 30% of rainfall falling from June to August. Annual rainfall distribution closely follows topography, rising from 1300 mm or less near the coast to approximately 2000 mm in the Kaimai and Mamaku Ranges and over 2200 mm in the Raukumara Ranges (Chappell, 2013). Days with more than 1.0 mm rainfall range from around 103 a year at Whakatāne to around 138 at Waihī (Chappell, 2013).

Vegetation has also played an important role in soil development. Changes in vegetation since the commencement of farming and commercial forestry have had considerable effects on properties such as soil stability.

3.4 Soil mapping

BOPRC has a near complete coverage of soils classification mapping for the region. The dataset is compiled from a range of surveys conducted by various sources, but the scale of each survey can vary. The majority of the region has been surveyed at 1:50,000, which is suitable for catchment analysis. More detailed surveys (1:15,000) have been conducted over discrete areas such as the lower Rangitāiki. These detailed surveys are more suitable for property scale analysis.

Most previous soil mapping work in the Bay of Plenty was carried out by the former Soil Bureau, a division of the Department of Scientific and Industrial Research (DSIR). In later years some other, mainly unpublished work was carried out by Landcare Research on behalf of BOPRC.

Each soil type has been analysed for ‘typical’ physical and chemical properties during the survey process. Drainage characteristics as well as texture and rooting depth are provided. Within the Rangitāiki WMA, the majority of soils are pumice with relatively large areas of podzolised, recent and allophanic soils. Higher rainfall and the presence of podocarp forests have led to the development of podzolised soils in the Urewera sections of the catchment. Approximately 95% of the catchment has good drainage characteristics and are resistant to wetting problems see (Figure 4).

Low lying areas to the north of the catchment are characterised by poorly drained gley soils. These soils tend to hold water more frequently which results in distinctive greying of the soil with mottles often appearing see (Figure 4).

There is full mapping coverage for the Rangitāiki WMA. Data is readily available through the GeoView 2 viewer and through Landcare Research’s publically accessible S-Maps site (http://smap.landcareresearch.co.nz/home).

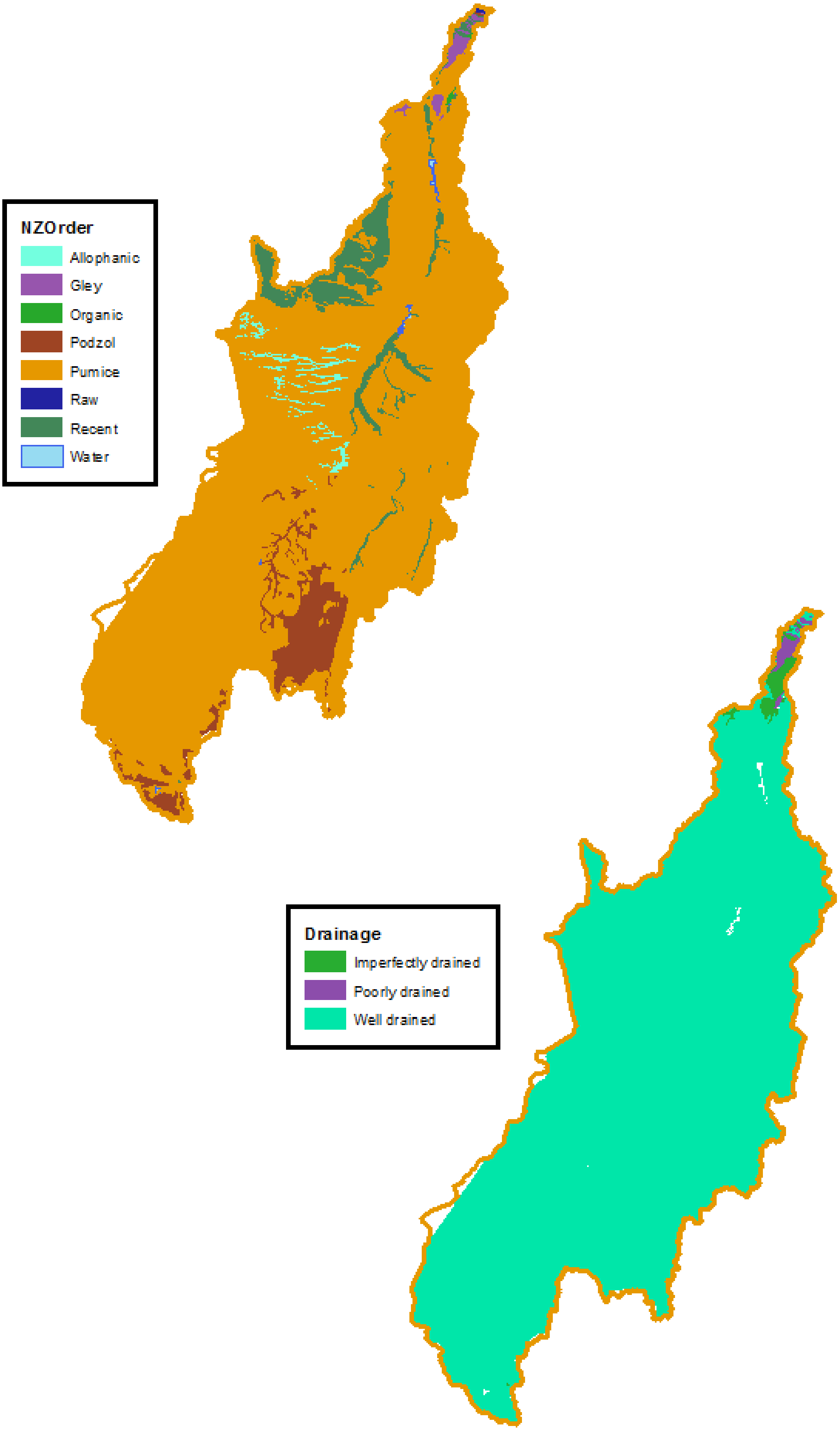


Figure 4 Soil orders and drainage characteristics within the Rangitāiki Catchment.

3.5 Soil monitoring in the Bay of Plenty

3.5.1 Trace elements

Trace element sampling has been monitored during BOPRC’s regular regional soil quality/health monitoring programme (Guinto 2009; 2010). This programme has monitored soil conditions at 47 sites (Figure 5). This programme was initiated in 2010 as a result of concerns regarding the potential risk of contaminant accumulation associated with some past and present-day land use practices such as fertiliser application and disease control. For example, cadmium is an unavoidable contaminant in phosphate fertilisers, facial eczema treatment contains high levels of zinc, and copper is used as a fungicide in orchards. Copper is also now commonly used to combat the recently discovered *Pseudomonas* bacterial disease (*Pseudomonas syringae* pv *actinidiae* or Psa) of kiwifruit. Other regional councils (e.g. Tasman, Marlborough and Waikato) have also included trace element sampling as part of their soil quality monitoring programmes.

Previous work on the trace element concentrations of soils in agricultural and horticultural areas of the Bay of Plenty (Solutions in Environmental Management (SEM) 2005) has indicated that copper and arsenic were the elements that most frequently exceeded the selected “trigger levels” or ”guideline values” for agriculture and residential land uses. Out of 103 topsoil (0-7.5 cm) samples analysed, an exceedance rate of 15.5% was found for copper and 13% for arsenic.

It is recommended that further investigation is carried out of agricultural and horticultural lands prior to development to more sensitive land uses such as residential. More recent research on kiwifruit orchards in the Bay of Plenty (Benge and Manhire 2011) has shown that, on average, the topsoil (0-15 cm) concentrations of trace metals were below the guideline values. However, concern has been expressed for arsenic, copper and cadmium as their average concentrations were close (50-63%) to their respective guideline values (NZWWA 2003). It was noted that arsenic could be potentially leaching into soils from treated posts, cadmium accumulating from phosphate fertilisers and copper from sprays used in orchards.

Samples for trace element analysis are taken from the existing soil quality monitoring sites and analysed for a range of metals. Archived soil samples have also been used to give data as far back as 1999/2000 for many sites. Data on trace elements have been reported on separately, with the most recent update in 2011.

Figure 5 shows the initial concentrations (1999/2000 sampling) of trace elements in farmed sites relative to initial background levels in indigenous forest sites (2000 sampling). This gives an indication of the degree of trace element contamination already associated with agricultural land uses at the commencement of the regional soil quality monitoring programme. With a few exceptions (e.g. arsenic, mercury), indigenous forest topsoils have lower concentrations of trace elements compared with farmed topsoils.

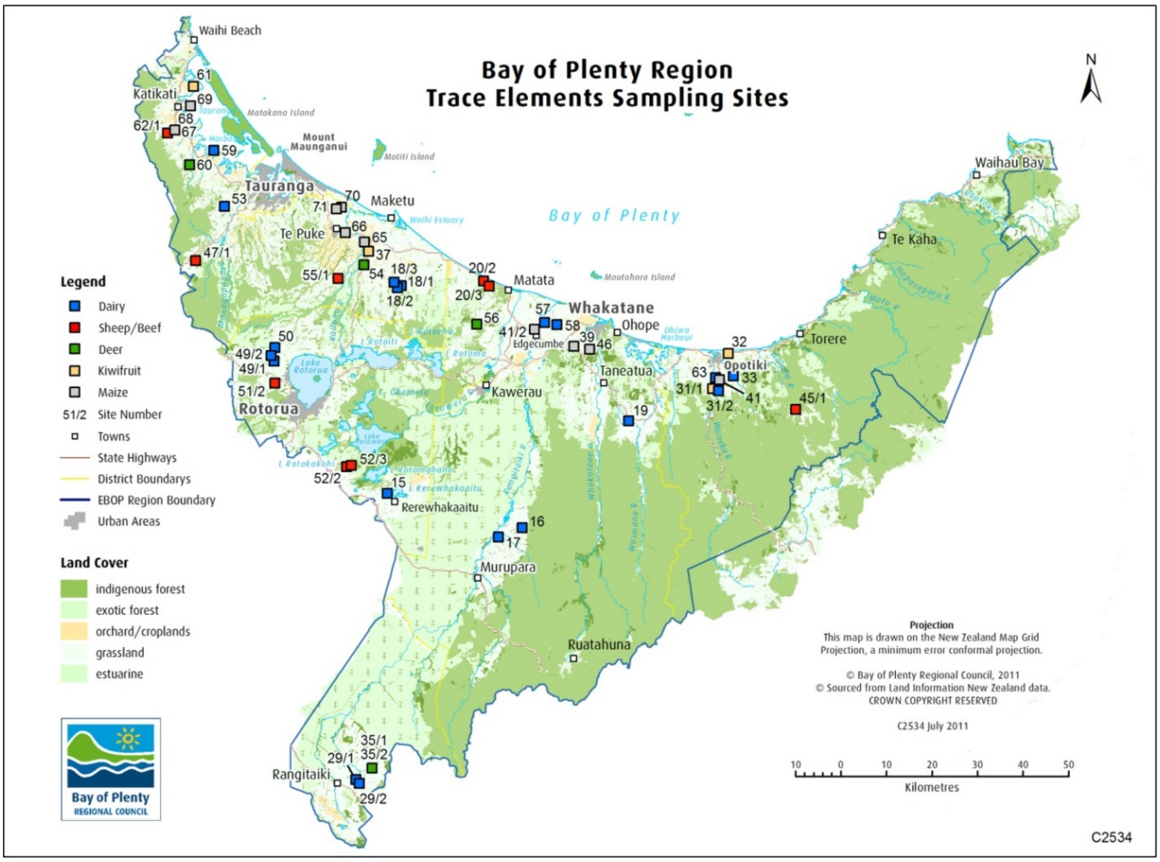


Figure 5 *Trace element sampling sites.*

Table 3 *Initial mean topsoil (0-10 cm) concentrations of trace elements (mg/kg) under farmed land uses relative to background levels in indigenous forests. Also shown are the NZWWA guideline values.*

Element	Indigenous forest 2000 (n =5)	Dairy 1999/2000 (N = 11)	Maize 2000 (n = 6)	Sheep/beef 2000 (n = 8)	Deer 2000 (n=4)	Kiwifruit 2000 (n = 6)	Guideline value (mg/kg)
Arsenic	6.4	5.3	6.2	7.1	2.8	5.3	20
Cadmium	0.08	0.68	0.23	0.38	0.60	0.65	1
Chromium	3.0	7.7	8.5	3.9	4.2	7.7	600
Copper	15.0	16.4	15.0	9.8	15.2	24.0	100
Lead	8.4	6.6	9.3	5.9	4.5	9.6	300
Mercury	0.14	0.07	0.069	0.08	0.05	0.08	1
Nickel	1.4	5.7	6.8	1.8	2.8	5.5	60
Uranium	0.52	1.43	0.90	0.82	1.05	1.18	23
Zinc	29.6	51.7	47.0	65.2	62.0	72.0	300

For the land uses monitored, many of the topsoil trace element concentrations were below environmental guideline values. Observed temporal changes in mean trace element concentrations were not significant. For dairy pasture sites, there were increasing trends in cadmium and zinc concentrations over a 10-year period (1999-2009) but these increases were not statistically significant. In fact, for cadmium, mean concentrations in 2004 (0.76 mg/kg) and 2009 (0.75 mg/kg) were almost identical suggesting that cadmium concentration has not increased since 2004. However, in the 2009 sampling, 26% (5 out of 19 sites) had cadmium levels exceeding the 1 mg/kg guideline value, which is a concern. In kiwifruit orchard sites, copper and zinc concentrations over the 10-year period (2000-2010) appear to be increasing but the increases were not statistically significant due to the small sample size. Nevertheless, this will most likely be a concern particularly for copper which is now a widely used spray to control the Pseudomonas disease (Psa) of kiwifruit vines.

Topsoil trace element concentrations were generally higher in agricultural land uses relative to background concentrations in indigenous forest sites reflecting that enrichment is attributable to land management practices that added detectable quantities of trace elements to soils.

Monitoring of trace elements will continue as part of BOPRC's ongoing NERMN soil monitoring programme and then next reporting round is due in mid-2015. This information will be critical in determining the impacts of PSA treatments during the recent 2014 outbreak and to determine whether longer term accumulation is occurring.

3.5.2 Soil health

BOPRC has established a monitoring programme to determine long-term trends in soil health across a range of land uses throughout the region. The programme was set up as part of the Ministry for the Environments (MfE) 500 Soils Project, of which Bay of Plenty contributed 75 sites. These sites have been maintained as part of the council's NERMN. The status of soil quality in the region has been reported periodically by Landcare Research (Sparling 2001; Sparling and Rijkse 2003; Sparling 2004; Sparling 2005; Sparling 2006a; Sparling 2006b) for all land uses and more recently by Guinto (2009) for dairy pasture and maize cropping sites.

The NERMN soils programme monitors a range of land uses to determine trends in long-term soil health. Land uses monitored include dairy, dry stocking, forestry, indigenous forests and deer (see Table 4 and Table 5). Two forestry sites that fall outside the catchment but are representative of values within the catchment have been included. The frequency of monitoring ranges from 10 yearly for forestry sites to three yearly for cropping sites. The frequency of dairy monitoring is currently five yearly, however this is likely to increase given the trends in fertility properties of the soils, as discussed below.

Trace element sampling of soils has more recently been included in the soil quality/health monitoring programme, due to concerns regarding the potential risk of accumulation associated with some past and present-day land use practices such as fertiliser application and disease control.

Table 4 Number of NERMN monitoring sites within the Rangitāiki WMA of different land use classes.

Land uses	**No. of NERMN sites**
Dairying	5
Deer	1
Forestry	6
Sheep/beef	1
Indigenous forests	1
Total	**14**

Table 5 Monitoring frequency for trace element analysis by land use within the Rangitāiki WMA.

	Dairy	**Maize**	**Dry stock**	**Forestry**	**Indigenous forest**	**Kiwifruit**
Monitoring frequency	5-yearly	3-yearly	5-yearly	10-yearly	10-yearly	5-yearly

Long-term monitoring data from the NERMN programme has identified that the amount of fertility nutrients (nitrogen and phosphorus) contained within topsoil is increasing to amounts that are classed as being high to excessive, due to the maximum utilisation by plants being exceeded. Excess nutrients in the soil profile increases the risk to receiving waters. Mean Olsen P values on dairy farms have been increasing consistently, and in 2014 were 99.8 mg/kg (see Figure 6). Nitrogen is also increasing steadily in dairy soils, with anaerobically mineralisable nitrogen and total nitrogen reaching the upper limits of optimal farm production (see Figure 7). The upper limit of pasture productivity is where the benefit to pasture growth diminishes and the risk to the environment increases. Not only does excess fertility lead to land managers making an economic loss it also increases the risk of contamination/eutrophication of nearby water bodies.

Kiwifruit sites as well as sheep/beef and deer sites have shown steady increases in Olsen P measurements. Kiwifruit sites had a mean Olsen P concentration of 106mg/kg in 2010.

Figures 8 and 9 show the long-term trends in fertility levels of soils in the NERMN programme. The upper desirable levels as described in the LMF guidelines are shown with orange and red lines. Further monitoring is required to obtain more data to provide greater confidence in soil health trends.

Soil health updates have been provided as a snap shot of the region and results have not been provided per site. Therefore further analysis would be required to delineate this information for the Rangitāiki WMA.

Published soil health updates are available on the BOPRC website (http://www.boprc.govt.nz/media/99812/2010_22__soil_quality_in_the_bay_of_plenty_2010_update.pdf).

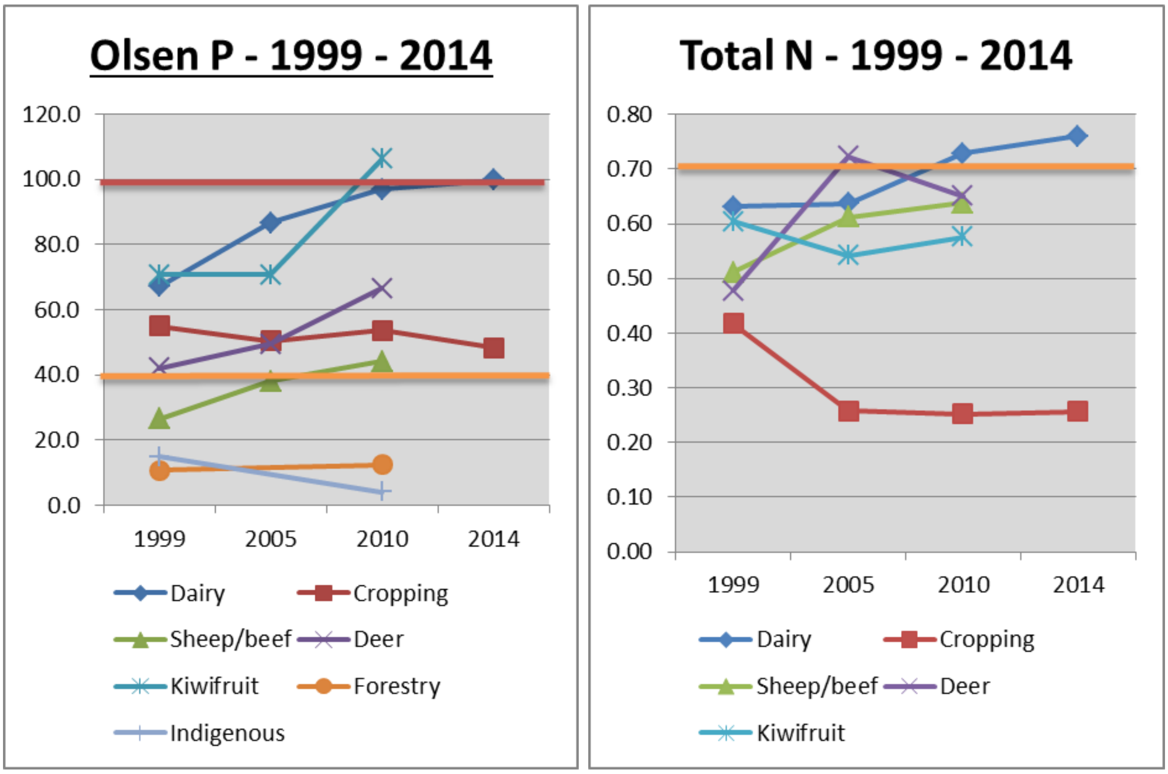


Figure 6 Olsen P and Total N trends across all land use types under the NERMN soils programme. Desirable values as described in the LMF manual are shown in orange and maximum production values (for Olsen P only) are shown in red.

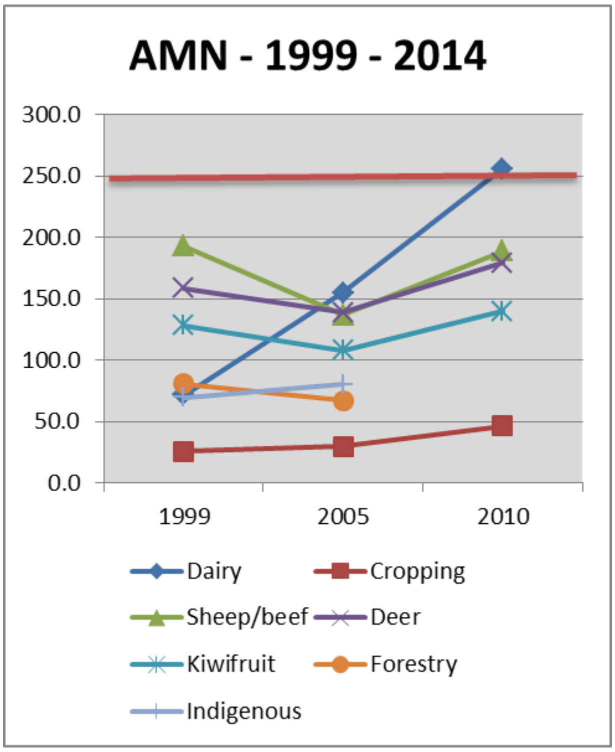


Figure 7 Anaerobically mineralisable nitrogen (AMN) trends across all land use types under the NERMN soils programme. The maximum production value as described in the LMF manual are shown in red.

3.6 Land Use

The New Zealand Land Use Map (LUM) was developed in response to New Zealand's obligations under the Kyoto Protocol and shows land use from 1990, 2008 and 2012. This map is focused on carbon accounting, primarily through distinguishing between forested areas and non-forested areas such as productive land. The map is a valuable resource to show land use change between major categories such as forestry to agriculture over a long time frame (22 years).

The Land Cover Database (LCDB version 4 (LCDB4)) shows much more detailed land cover information over a shorter timeframe - from 1996, 2001, 2008, 2012 (16 years). The LCDB4 is a valuable tool to show more subtle changes in land use and is able to provide more detail than the LUM. A comparison of land use categories between the two datasets is outlined in Table 6.

Table 6 Comparison between land use categories of LCDB and LUM.

LCDB4 – 1996-2012	LUM – 1990-2012
Broadleaved indigenous hardwoods	Natural forest
Built-up area (settlement)	Grassland - high producing
Deciduous hardwoods	Grassland - with woody biomass
Estuarine open water	Cropland - perennial
Exotic forest	Grassland - low producing
Forest - harvested	Other
Gorse and/or broom	Wetland - open water
Gravel or rock	Planted forest - pre-1990
Herbaceous freshwater vegetation	Cropland - annual
Herbaceous saline vegetation	Settlements
High producing exotic grassland	Wetland - vegetated non-forest
Indigenous forest	
Lake or pond	
Low producing grassland	
Mangrove	
Manuka and/or kanuka	
Matagouri or grey scrub	
Mixed exotic shrubland	
Orchard, vineyard or other perennial crop	
River	
Sand or gravel	
Short-rotation cropland	
Surface mine or dump	
Transport infrastructure	
Urban parkland/open space	

Approximately 78% of the Rangitāiki WMA is currently in forestry, either plantation (55%) or indigenous (25%) - see Table 7 and Figure 8.

Currently only 15% of the catchment is in highly productive grassland and there is a very small proportion of urban areas (0.04%). The large proportion of exotic forest areas in the catchment could potentially lead to land use pressures in the future through land use conversions, similar to what has occurred in the Kāingaroa Forest.

It is not clear what the change in composition of catchment land use has been over time. This exercise has been proposed as a recommendation for future work.

Table 7 Land cover database analysis of the Rangitāiki WMA.

LCDB4 – 1996-2012	**Area of catchment (ha)**	**% of total catchment**
Broadleaved indigenous hardwoods	3,476	1.2%
Built-up area (settlement)	359	0.1%
Deciduous hardwoods	589	0.2%
Exotic forest	131,200	44.4%
Fernland	194	0.1%
Forest - harvested	24,735	8.4%
Gorse and/or broom	995	0.3%
Gravel or rock	63	0.0%
Herbaceous freshwater vegetation	833	0.3%
Herbaceous saline vegetation	3	0.0%
High producing exotic grassland	44,288	15.0%
Indigenous forest	73,499	24.9%
Lake or pond	498	0.2%
Landslide	18	0.0%
Low producing grassland	4,134	1.4%
Manuka and/or kanuka	5,764	2.0%
Matagouri or grey scrub	15	0.0%
Mixed exotic shrubland	163	0.1%
Orchard, vineyard or other perennial crop	531	0.2%
River	432	0.1%
Sand or gravel	5	0.0%
Short-rotation cropland	3,153	1.1%
Surface mine or dump	47	0.0%
Tall tussock grassland	9	0.0%
Transport infrastructure	477	0.2%
Urban parkland/open space	105	0.0%

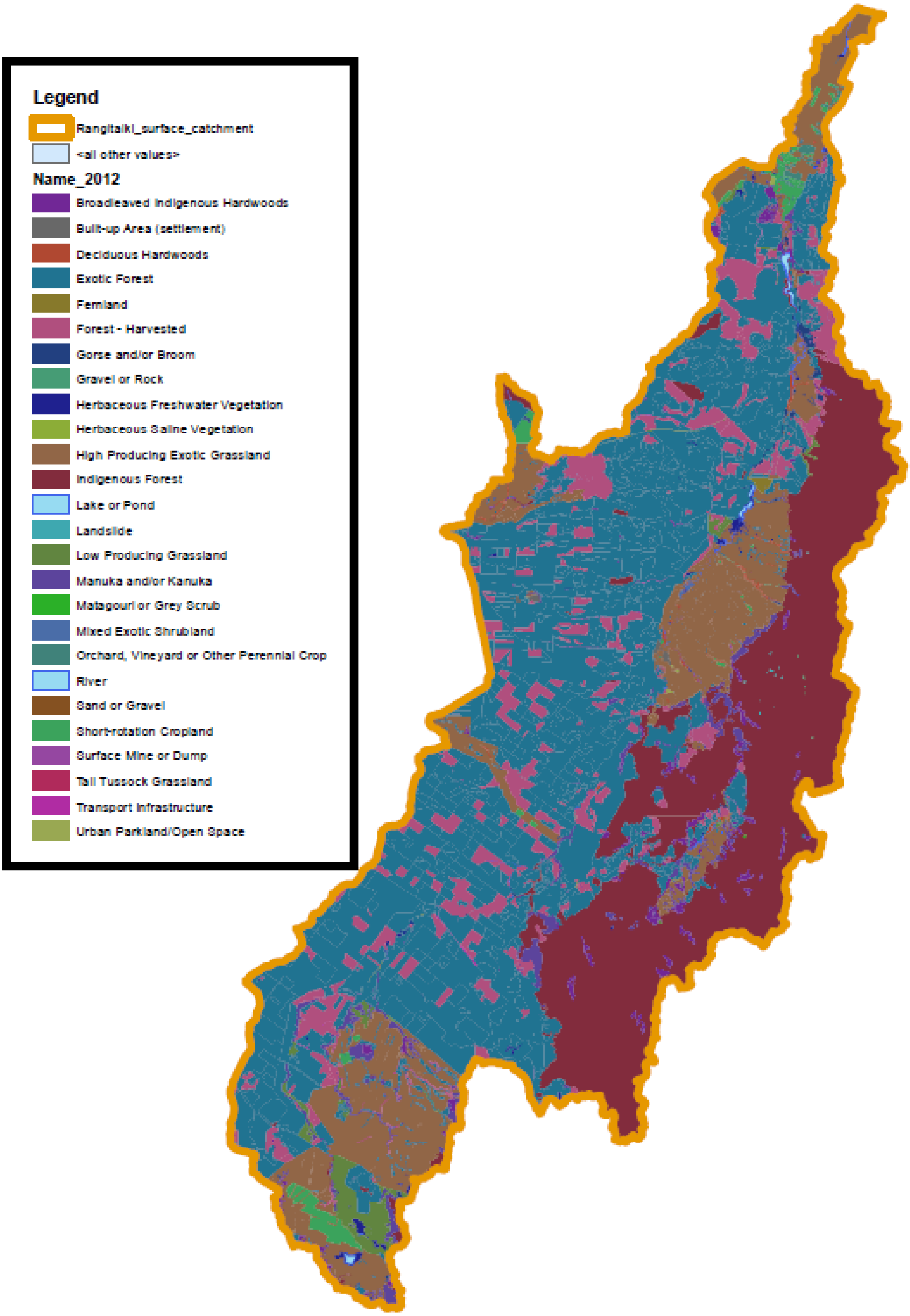


Figure 8 LCDB4 map of Rangitāiki WMA (2012).

3.6.1 Catchment Land Use for Environmental Sustainability

The National Institute of Water and Atmospheric Research (NIWA) and the Ministry of Agriculture and Forestry (MAF) have developed a GIS based modelling system called Catchment Land Use for Environmental Sustainability (CLUES) that assesses the effects of land use change on water quality and socio-economic indicators. The model allows users to create both land use and farm specific scenarios and to predict loading of phosphorus and nitrogen in waterways, and displays results in graphical and tabular formats. Some specific training would be required, but the model is available in house, utilising already available software.

3.6.2 Land Use Capability mapping

The Land Use Capability (LUC) Classification is defined as a systematic arrangement of different kinds of land according to those properties that determine its capability for long-term sustained production (Manderson et al. 2009).

The LUC system builds on the Land Resource Inventory to categorise land into eight classes according to its long-term capability for production (Manderson et al. 2009). This dataset provides valuable information about the physical quality of the environment and also provides an indication of land uses that would be more suitable for a particular parcel of land.

This dataset makes it possible to analyse how land is currently allocated in terms of current land use and mapped capability Optimal land allocation can be subjective and is dependent on a number of external factors, such as tenure and land ownership, but broadly speaking is the allocation of the most intensive land uses on the most productive land. Poorly allocated land would be high intensity land uses such as dairying and cropping on land that has low productive capability, due to one or a number of factors. Plantation forestry on highly productive land could also be an example of poorly allocated land.

In reality, it is not possible to achieve optimal land allocation, but determining the level to which land uses within a catchment are aligned with the capability of the land is a valuable indicator of the current land use pressures within that catchment.

A more detailed analysis of the catchment should be conducted to determine how current land use is allocated according to the LUC categories. This analysis has been recommended for future work.

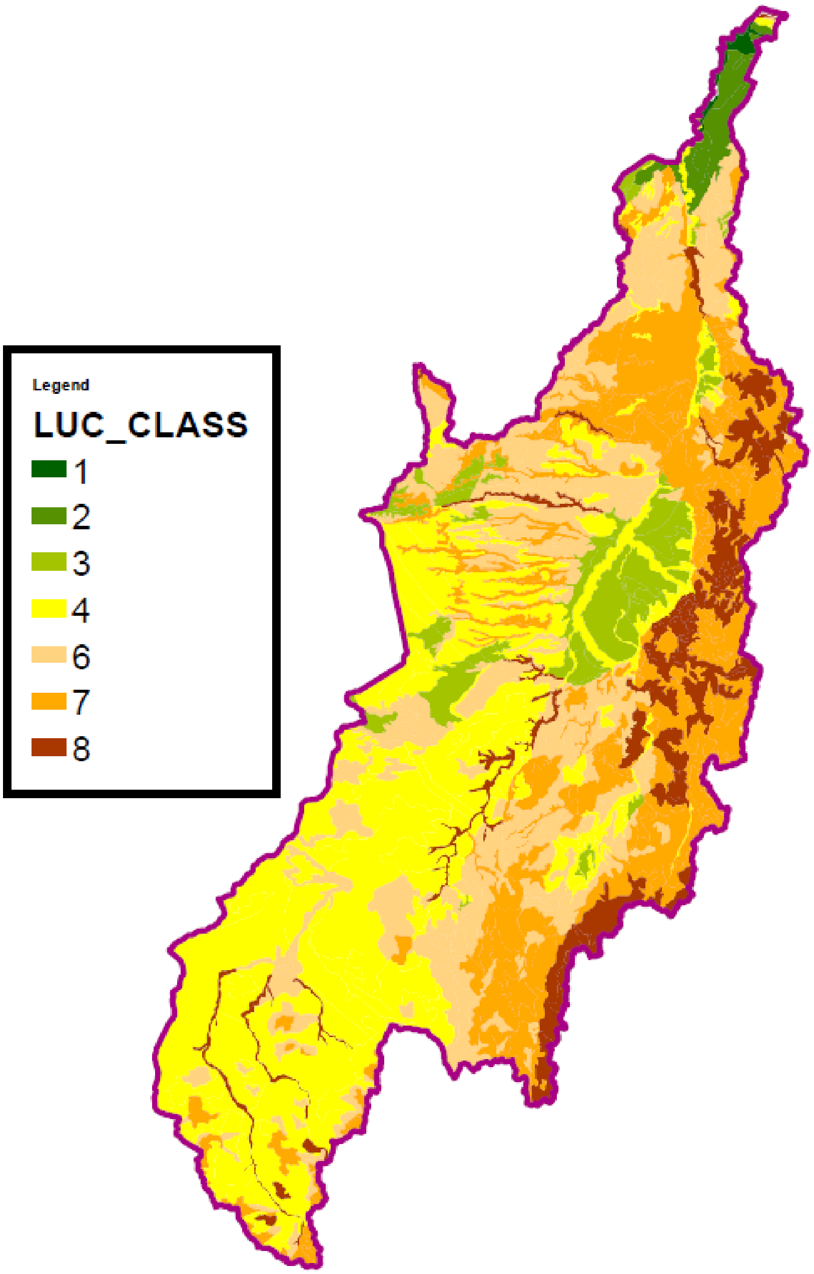


Figure 9 Land Use Classification map of Rangitāiki Catchment.

3.6.3 Light Detection and Ranging

Light Detection and Ranging (LiDAR) is a remote sensing technology that provides high resolution topography of a site. It provides the ability to spatially represent slopes with a high level of accuracy. Accurate slope information is critical to cross checking other sources of information that utilise slope as a key determinant, e.g. Land Use Classification. Light Detection and Ranging (LiDAR) information is currently available for the entire Rangitāiki Catchment. The accuracy and resolution provided is adequate for use in the current state project. Complete coverage of the region has been obtained in 2006/2007 and again in 2011/2012. These datasets will allow more accurate analysis of erosion and land stability over time. To date, this information has not been used to monitor land stability formally.

3.7 Gaps and recommendations

It is critical to understand pressures arising from land use change/intensification both to comprehend the likely causes of existing downstream impacts on ecological values such as receiving waters, and also to pre-empt future problems and manage them accordingly. Without appreciating land use pressures it is difficult to manage values, including those relevant to freshwater (see Figure 10).

Determining the current state of soils is also critical in understanding the impacts of land use change on ecological values. The primary impacts observed on receiving waters in the Bay of Plenty, arise from eutrophication processes occurring from increased fertility of nitrogen and phosphorus and from erosion and sedimentation from land to waters.

Many land managers are aiming to achieve optimal production within their operations, which often involves the use of fertilisers and irrigation techniques. Fertilisers can have unintended impacts such as the accumulation of trace elements in the soil and loss of nutrients to receiving environments. The accumulation of trace elements in the soil can impact on the plants growing in the soil and the animals grazing on that land.

Soil stability, particularly in close proximity to waterways, is highly important to managing the ecological values of our waters. An initial study of soil stability, including identification of high risk areas, should be undertaken.

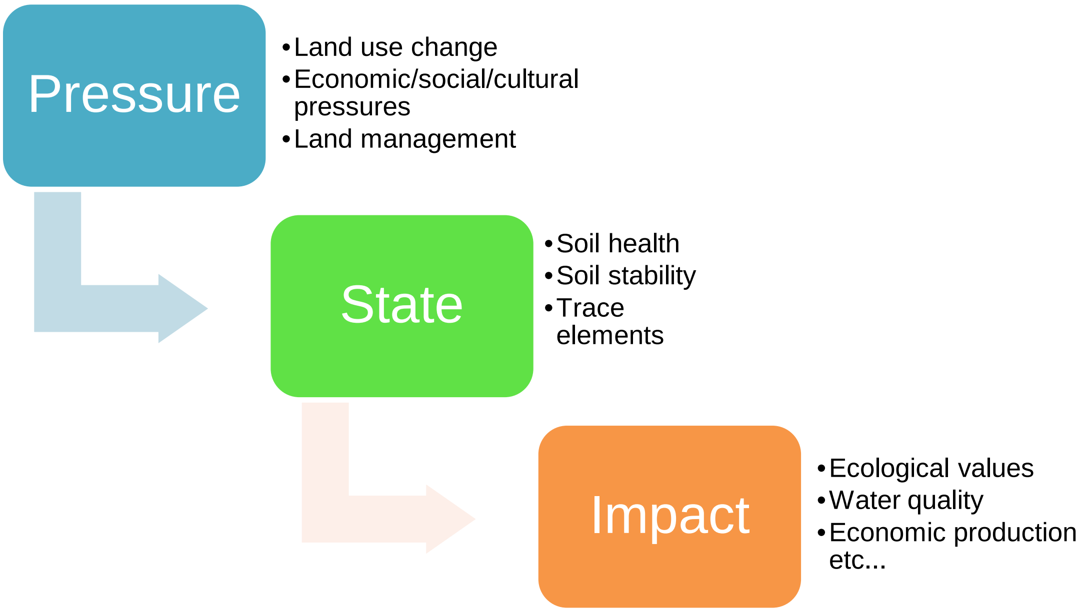


Figure 10 Land management process flow diagram.

The NERMN soil health programme is a critical source of information about trends occurring within topsoil which is a direct indicator of the land management practices occurring. As part of the Rangitāiki WMA limit setting process, it would be a valuable exercise to run a pilot sampling programme to obtain detailed background information on the current condition of the catchment, in relation to the soil quality indicators. While it would not be possible to identify trends from a single sampling period, it would be possible to determine the status of soil quality indicators within the catchment for particular land uses.

There is a primary gap in knowledge of the interactions between land use - soil health - land management and ecological impacts (see Figure 10). Although BOPRC has data available to begin formally monitoring land use pressures and emerging trends in soil health, obtaining information that provides a clearer picture between land use change, soil health, and resultant effects on aquatic ecosystems is more difficult. A detailed analysis of the Rangitāiki Catchment should be conducted to identify land use change over time and provide more detail around how land use may be impacting on water quality within the catchment.

The link between increasing concentrations of nutrients within the soil profile and impacts on downstream water bodies is currently not clear. Further work is required to link land use pressures and soil health to ecological impacts within receiving waters. This involves complex process and interactions but is critical to better understand the drivers of water quality within these catchments. Setting up localised trials and focussed study sites where programmes of co-ordinated science monitoring is conducted across disciplines would greatly assist in this process. This leads to an opportunity to have ‘sentinel sites’, whereby detailed and coordinated monitoring is undertaken of groundwater, surface water (including quantity and quality), soil attributes (including nutrients), and ecology (periphyton, invertebrates and fish).

Identifying broad changes in land use, for example from forestry to pasture, is possible through spatial analysis and using nationally available datasets. There is currently no formal reporting or monitoring of land use change, however, due to the availability of national datasets, it is possible to monitor change within specified catchments and report on findings. Such an analysis was recently conducted in the Rangitāiki Catchment between 1996/1997 and 2001/2002 by Landcare Research (Boubee et al. 2009). This study outlines that while the catchment was relatively stable during this period, there is a significant risk from conversion from forestry to productive grassland, poor management of forestry, and intensification of existing agriculture.

Land use intensification and land management practices, particularly subtle changes such as winter support for dairy on dry stock farms, is much more difficult to monitor and often requires input from land holders and other local knowledge. This information is pertinent to identifying land use pressure in the catchments. It is recommended that the efficacy of methods to monitor land use intensification over time be investigated.

A point that is worth noting is that sieving of soil particles greater than 2 mm prior to analysis has been raised as a potential issue in obtaining accurate Olsen P readings on pumice soils (Rajendram *et al*. 2011). It is worth investigating the potential impacts of this on the results obtained from the NERMN soils programme to date. There may be an ability to use this information to determine whether Olsen P tests have overestimated the amount of phosphorus available to plants. The laboratory used for soil chemical properties has not been changed since the commencement of the monitoring programme; therefore any trends in Olsen P concentrations identified in the NERMN programme are still valid. If any overestimation is found, then it should be relatively straight forward to adjust results.

The NERMN soil monitoring programme has been running since 1999 and three to four monitoring periods have been obtained for most land uses monitored. Fertility indicators on dairying sites have been trending upwards and a number of sites are showing levels of fertility that are deemed to be excessive (LMF guidelines, 2009). To get better clarity on this trend, it is recommended that monitoring of dairy and kiwifruit sites be increased to every three years from the current five years. Having this improved dataset will show/confirm any emerging trends more accurately and greatly improve our decision making ability. Soil fertility above certain measures represents an economic loss to the farmer, so any readjustment to more suitable levels could have significant environmental as well as economic implications.

To facilitate the NERMN soil health monitoring programme, the location of each site remains confidential between BOPRC and individual landowners. This makes it difficult to provide analysis at any level finer than regional scale. Regardless of this, the low number of sites available within each WMA would make it difficult to draw any conclusive trends emerging from the reduced dataset. The baseline analysis recommended above would fill this gap and allow a baseline in soil state to be determined.

Soil stability is not currently monitored effectively within the region and is critical in understanding sediment loads likely to enter waterways. The Land Monitors Forum provides a methodology to be followed by regional councils to assess soil stability. A number of regional councils currently monitor soil stability as part of their ongoing state of the environment reporting. The monitoring process involves analysing aerial photography and is a desktop exercise. It does, however, require an analyst with advanced aerial photography analysis skills to conduct the monitoring. It is recommended that a baseline soil stability assessment be conducted over the Rangitāiki WMA. Unpublished information may be available to provide an initial comparison of soil stability over time.

Soil Fauna populations are poorly understood in the region as an indicator of soil health. The Land Monitoring Forum is running a pilot programme to determine the level of protectiveness required for soil fauna. The presence of soil fauna is closely linked to organic soil carbon, which is a key driver of soil nutrient status and soil moisture. Soil fauna populations in the WMA need to be investigated through obtaining baseline information from various land uses and reference sites. The prevalence of dairying land uses within the WMA increases the importance of a more detailed picture of soil health.

BOPRC's lysimeter network provides valuable information of moisture flow through the soil profile and if utilised, can provide an indication of the expected leaching rates of particular soils when combined with other metrics. To improve knowledge of drainage and potential leaching (N and P) from local soils, the existing soil lysimeter network could be leveraged to determine leaching rates within pumice, allophanic, and recent soils these catchments. If this data was obtained over a three year period, it would allow modelling to be calibrated more closely to locally occurring soil types.

A key recommendation for land use and soil health moving forward is to align current land use and monitoring and reporting into categories as presented in Figure 10 above. This will provide the organisation and the public with a clearer view on what is being measured and the relationship between land use, soil health and ecological impacts. The recommendations arising from this review are summarised in Table 8.

Table 8 Table of soil health and land use recommendations for the Rangitāiki WMA.

Gap theme	Gap	Recommendation
Improvements to methods and reporting	No formal methodology/reporting mechanism currently exists to monitor and report on land use pressures. Intensification of land through activities such as dairying support on a predominantly dry stock block needs to be better understood / monitored.	Develop a standard methodology for monitoring and reporting on land use pressures using a range of nationally available datasets including LCDB, LUM, Stats NZ data, NERMN, Agribase etc. The reporting frequency of such reports will be limited to the availability of the underlying data and therefore a return period of less than 4-5 years is unlikely. Investigate combining detailed farm knowledge with land use pressure monitoring. Investigate alternative information sources such as Agribase and Statistics New Zealand. This information is likely to confirm how rapidly land use pressures have emerged over time and outline the current state of the WMA. Without this information it is not possible to robustly analyse how changes in land use may have impacted on ecological values within the catchment. It will also not be possible to determine the key economic drivers within the catchment and to determine what impact mitigation measures would likely have.

Gap theme	Gap	Recommendation
Data for models	There is a need to identify what role pumice/gravelly soils play on nutrient loss and leaching. Overseer is used extensively to model nutrient loses, but is poorly calibrated to local conditions in the Bay of Plenty.	Conduct a detailed review on the available literature on pumice soils. Rajendram *et al.* (2011) have conducted a preliminary study on the impact that laboratory methods can have in overestimating Olsen P in pumice soils. Need to develop a programme to better understand the role of leaching in our most prevalent soils (pumice, allophanic and recent) and investigate utilising/leveraging off our existing lysimeter network and input into the planning for proposed lysimeters to better understand leaching in the region and these catchments. Landcare Research should be consulted to ensure any data obtained is suitable for calibrating Overseer modules. Overseer is used extensively to model predicted leaching rates and therefore without this information it is not possible to provide a high degree confidence in the outputs produced for certain soil types and climatic zones.
Improvements to methods and reporting	Identify NERMN soil health monitoring results for each specific WMA.	Develop a database for existing NERMN data that allows comparisons of individual sites as well as between distinct geographic areas such as WMAs. The number of sites available in any particular area will dictate how robust the data is. A valuable data resource exists as a result of the NERMN soil health monitoring programme. The programme was designed to provide a region wide snapshot as opposed to specific soil types or catchments. See below comments on obtaining baseline information for each WMA.
Data management	Include trace elements as part of the standard NERMN monitoring suite.	Trace elements are currently reported on separately from the soil health programme. They should be included in the regular NERMN monitoring and reported on in the regular soil health updates.
Improvements to methods and reporting	Dairy and kiwifruit are showing trends in soil health that need to be better understood.	The initial NERMN monitoring programme was designed around monitoring those land uses with the greatest soil disturbance. After multiple monitoring periods, it is evident that it is more appropriate to monitor the most intensive land uses more frequently and potentially reduce monitoring of those land uses that were previously more frequently monitored. It is recommended to increase the monitoring period of dairy and kiwifruit to 3 yearly.
Data for models	Do not currently have the ability to predict the effects of land change on water quality.	First phase model to allow interactive discussions on land use change scenarios and impacts on water quality with stakeholders. Catchment Land Use for Environmental Sustainability (CLUES) has been recommended as a suitable model which can be built and run in-house if desired.

Gap theme	Gap	Recommendation
Identify values	Cultural pressures on land are not clearly understood at this stage.	Investigate whether cultural pressures can be readily identified and incorporated into land pressures monitoring. This would involve reviewing available information sources and the robustness of any such information. It should be noted that other groups within BOPRC are investigating this work, so it is suggested as a desktop exercise to determine how readily this information could be included with other metrics.
Obtain new data	When reviewing the information available from the NERMN programme it is evident that that are relatively few representative sites per WMA.	The amount of soil health information available per WMA is relatively low. It is recommended that a pilot programme is conducted to take a snap shot of soil health in the WMA. This would indicate the number of sites that are currently exceeding soil health criteria, particularly relating to fertility (nitrogen and phosphorus). The number of sites included in such a programme would need to be statistically robust enough to enable extrapolation across the WMA. If combined with land use monitoring above it will provide a powerful tool for assessing the state of the WMA. Any such monitoring programme should also include additional parameters (water quality etc) to provide a complete picture.
Improvement to methods and reporting	The link between land use pressure, soil state and water quality is not clearly understood.	The science team should work on identifying linkages between land use pressures/soil health and water quality / ecological values. While good information exists within each discipline there have been few linkages drawn. Given that land use change can be slow to occur and any exercise linking pressure and state with Impact would be complex it would be recommended to take a long-term view on any analysis.
Obtain new data	Soil stability characteristics are not known within these WMAs.	Assess soil stability, soil intactness and soil disturbance across a range of land uses over time. This analysis will help to determine whether the soil is: • stable, • unstable but inactive (erosion prone), • recently eroded, or • freshly eroded. This information will provide a framework for assessing land use disturbance due to land use. Phosphorus is a key contributor to eutrophication processes, yet the loss of soil sediments to receiving waters is not well understood within the WMA. This information is critical to understanding the loss of productive soil, but also the potential for impacts on ecological values. This information could be combined with baseline soil health data to provide an indication of the state of the catchment.

Gap theme	Gap	Recommendation
Obtain new data	Soil microbial/fauna populations.	Soil organic matter can play a significant role in managing nitrogen in the topsoil. This is a double benefit of allowing more nitrogen to be available to the plants while reducing the amount lost to leaching. Soil fauna populations are not well understood within this WMA and baseline information should be obtained.
Improvements to methods and reporting	Need to monitor economic production from particular land.	This will allow us to determine the economic productivity of particular land uses and also to predict the likely impacts on the economy when making decisions about nutrients targets. Key reporting metrics would need to be decided.

Part 4: Hydrology

4.1 Introduction

The hydrological profile of the Rangitāiki River is significantly modified due to the hydroelectricity dams and the actively managed hydro lakes (Matahina and Aniwaniwa). Implementation of the NPS-FM requires understanding of hydrology of the catchment, including interactions between water bodies (e.g. streams and groundwater), in order to set environmental flows and levels. This section outlines our current hydrological monitoring programme and identifies gaps.

As part of the NERMN programme, continuous flow information from eight continuous stations is collected throughout the Rangitāiki WMA. These sites provide detailed information on a river's flow regime (where rating curves are available) or river's stage (where rating curves are unavailable). Flows are monitored for a number of reasons, including monitoring high flows for flood forecasting, and monitoring low flows to help set minimum flows for water allocation purposes. Because it is expensive and impractical to establish water level recorders in all rivers throughout the region, BOPRC is relying on producing flow correlations between permanently gauged sites and ungauged catchments to build better relationships to flows in ungauged catchments.

The calculation of low flow statistics for ungauged sites is based on a statistical relationship between the gauged sites and the ungauged sites. An additional 15 monitoring sites are thus gauged during the summer to obtain statistics on low flow variables. These low flow sites are used to correlate the flow in the ungauged catchments to a permanently gauged monitoring station in order to provide flow statistics in catchments without a permanent gauging station.

4.2 Hydrological monitoring in the Rangitāiki WMA

The surface water hydrology science programme has been reviewed by Fernandes (2015), and so only the salient points of relevance to the Rangitāiki WMA are discussed here. The current state of hydrological monitoring stations throughout the Rangitāiki WMA is reviewed, and recommendations for future work made. Information on available gauging stations can be found in Table 9 and Table 10 provides details on the associated flow statistics.

Table 9 Hydrological characteristics of the Rangitāiki WMA, showing the continuous gauging stations and locations of low flow sites.

Rangitāiki WMA*
Area: 295,584 ha
Number of sub-catchments: 10
Low flow sites: 12
Gauging stations: 8
Rangitāiki at Aniwhenua[1]
Rangitāiki at Matahina[1]
Rangitāiki at Murupara
Rangitāiki at Noord Veirboom[2]
Rangitāiki at Rabbit Bridge[3]
Rangitāiki at Thornton
Rangitāiki at Te Teko
Whirinaki at Galatea

* Disclaimer: Data is the latest available. In some instances this may be over 10 years old and will need to be upgraded. Data is not to be used for allocation purposes and is intended for use in this report only. No liability is assumed for data within this report.

[1] Part of the Trust Power scheme, data may be available and useful to determine volumes but flow will be dependent on the dam operations.

[2] Information on GIS layers indicates a Level and rainfall station. Unable to find additional data on this station.

[3] GIS indicates a level only site. Available on line on BOPRC live monitoring. May need to establish rating curve.

Table 10 Rangitāiki Water Management Area Low Flow Summary.

Catchment	**River/stream**	**Site name**	**Q5 7day l/s**	**MALF l/s**
Horomanga	Haumea	Galatea Road Bridge	880	925
Horomanga	Haumea	Magee's Farm	375	475
Horomanga	Horomanga	Galatea Road Bridge	460	-
Horomanga	Mangakotukutuku	Van dan Broek Farm	95	110
Horomanga	Mangamutu	Taylor's Farm	50	60
Horomanga	Ruarepuae	Waitaruna Road	284	316
Horomanga	Ruarepuae South Tributary	Bannan's Farm	30	50
Mangamako area	Mangahouhi	Galatea Road	50	70
Mangamako area	Waihua	Gorge	293	-
Waikowhewhe area	Rangitāiki	Te Teko	37,647	41,399
Wheao	Rangitāiki	Murupara	12,562	14,317

Catchment	River/stream	Site name	Q5 7day l/s	MALF l/s
Whirinaki	Whirinaki	Galatea	3,692	4,687
* Data is the best data available. Current data is available however analysis on the latest data is not complete. Data Services is in the process of updating this information In some instances this may be over 10 years and will need to be upgraded. Data is not to be used for allocation purposes and is intended for use in this report only. No liability is assumed for data within this report.				

The Rangitāiki WMA can be divided into a number of "surface drainage catchments", consisting of the greater catchment (in this case the Rangitāiki WMA), and the primary, secondary and tertiary catchments. The tertiary catchment is generally at the level of an individual river, whilst the secondary and primary catchments are amalgamations of these into larger spatial areas.

To determine whether any extra hydrological stations are needed in these tertiary catchments, each catchment has been individually assessed based on its geology, catchment area, established relationships between gauged and ungauged catchments, and the number of consents already issued within that catchment.

Analysis of this information was used in order to make recommendations on whether flow monitoring should occur in any of these tertiary catchments. For example, any catchments with a drainage area of 5,000 ha or less can be gauged on a case by case basis, and when needed. Catchments with a drainage area between 5,000 and 10,000 ha will need and interim gauging programme. Catchments that are greater than 10,000 ha will need to have a permanent gauging station set up, and regularly gauged. Any catchments without water allocation pressure and with little or no current consented abstraction were also deemed to be of a lower priority to gauge than catchments which are subject to high allocation pressure and have a high number of consents issued.

Table 11 provides a summary of the recommendations for all catchments within the Rangitāiki WMA.

Table 11 Summary of the recommendations for all catchments within the Rangitāiki WMA.

Current flow sites?	Sub-catchments	Recommendation
No	Kaingaroa	Establish gauging site
No	Mangatiti, Pokairoa, Otamatea, Pouarua	No need for flow monitoring currently
Yes	Horomanga, Whirinaki, Wheao, Mangamako	Need more gaugings at existing sites
Yes	Waikowhewhe	Influenced by dams, continue to monitor and estimate baseflow

[1] Catchments <5,000 ha. Can be gauged on a case-by-case basis when needed

NIWA has also developed a database of flow statistics for all reaches throughout the Bay of Plenty region (Booker et al. 2014), giving us the ability to look at modelled flow statistics in the Rangitāiki WMA. Many of these flow statistics reflect ecologically important parts of a rivers flow regime that are known to greatly influence algal, invertebrate and fish communities. For example, the frequency, magnitude and duration of both floods and low flows can have profound effects on river ecology. Based on these modelled flow statistics, it would be possible to examine how variable these ecologically relevant flow parameters are throughout the Rangitāiki WMA, and ensure that we are monitoring sites that cover a range of these parameters.

Parts of BOPRC's responsibilities revolve around setting minimum flow and allocation limits in rivers subject to abstraction. Water is abstracted for a variety of uses, including town supply, irrigation (for both pasture and horticulture such as kiwifruit), dairy shed use, and frost protection.

Under the current Regional Water and Land Plan (RWLP), clear processes and methods exist for minimum flows to be set in waterways. Of particular relevance are Methods 177 and 179. Under Method 179, a default in stream minimum flow has been set to 90% of the Q_5 7-day low flow. This means that 10% of the Q_5 7- day low flow is available for abstraction. This simple hydrology based method is based on the assumption that the degree of habitat protection within a river is linearly related to the amount of water within a river, and that setting a minimum flow of 90% of that which occurs naturally once every five years over a seven-day period is unlikely to have any adverse ecological effects.

For ecological minimum flows, the 'In Stream Flow Incremental Methodology' (IFIM) is used. This method calculates the weighted usable area of fish habitat for different fish species in each river, and sets the minimum flow based on the protection of a specific level of habitat that is found at the streams Minimum Annual Low Flow (MALF). This is a robust methodology that has been used to set ecologically relevant low flows throughout the Bay of Plenty (Jowett 2012). Currently, BOPRC has undertaken detailed IFIM surveys in 57 rivers throughout the region. Of these, eight were in the Rangitāiki WMA (

Table 12). Finalised minimum flows in these eight sites have to be recalculated using RHYHABSIM and the new methodology as suggested by Jowett (2012). This revised methodology bases habitat retention relative to a stream's MALF, instead of relative to a stream's median flow (which is what the current RHYHABSIM calculations are based on).

Table 12 List of the eight sites in the Rangitāiki WMA where detailed IFIM analyses have been undertaken and where minimum flows have been set to protect specific ecological values. Note that the final IFIM minimum flows have yet to be calculated for these sites, based on habitat retention relative to a stream's MALF, instead of relative to a stream's median flow.

River	**MALF (L/s)**	**Q5 7-day low flow (L/s)**	**Default minimum low flow (L/s)**
Haumea @ Galatea	925	780	702
Haumea @ Magee's	475	375	337.5
Mangakotukutuku	110	95	85.5
Mangamutu	60	50	45
Ruarepuae @ Bannans Farm	50	30	27
Ruarepuae @ Waitaruna	300	250	225
Upper Rangitāiki at Galatea	20,600	17,800	16,020
Whirinaki	5,200	4,300	3,870

4.3 Gaps and recommendations

Identified gaps are summarised in Table 13. A significant resourcing challenge is obtaining satisfactory coverage of the region with continuous flow monitoring sites. Currently, continuous flow recorders operate at eight sites throughout the Rangitāiki WMA, and there may be a requirement to increase this number slightly. In lieu of setting up permanent flow sites, a series of spot flow gaugings can be undertaken in a range of other rivers in the area, with the aim of developing good correlations between permanently gauged and ungauged catchments. Analysis of the proposed water allocation surface water catchments has identified a number of these where such spot flow gaugings are recommended.

Given the importance of stream hydrology to ecological communities, and the realisation that it is impossible to monitor flows in all waterways throughout the Rangitāiki WMA, the importance of hydrological models in providing estimates of ecologically relevant flow statistics cannot be over-emphasised. Of relevance to water allocation and the setting of low flows is the use of the NIWA EFSAP model. This tool is currently undergoing validation at sites where detailed IFIM surveys have been done throughout the region.

Table 13 Identified gaps for hydrological monitoring and recommendations to fill gaps.

Gap theme	**Gap**	**Recommendation**
Spatial frameworks	Firm guidance as to what an appropriate spatial framework would be for stream hydrology.	Examined the appropriateness of the proposed catchment-based classification as freshwater management units for hydrology, and contrast this to other spatial frameworks that could be used for water quality and ecology.
Data for models	Inadequate coverage of data within geological provenances for comparison of water resource monitoring data.	Expand the geological portion of the REC to include more classes.

Gap theme	Gap	Recommendation
Obtain new data	Lack of monitoring sites within geological provenances.	Target groundwater systems (aquifers) by installation of bore fields, for comprehensive monitoring and data comparison. This includes groundwater – surface water interaction.
Obtain new data	Improve calculated statistical relationships between continuously gauged and ungauged catchments.	Continue flow monitoring within catchments that do not currently have a permanent gauging station.
Obtain new data	Lack of flow monitoring in catchments where this has been identified.	Implementing new flow monitoring sites as needed.
Obtain new data	Contribution of groundwater (quality and quantity) to waterways.	Investigate the contribution of groundwater to waterways (springs, base-flow to rivers and wetlands) within the Rangitāiki WMA and the relative nutrient load contributed from groundwater sources.
Obtain new data	Need for improved understanding of infiltration rates to subsurface storage.	Maintain and monitor existing sites until robust statistical relations have been developed. Install new sites to obtain adequate coverage.
Obtain new data	Lack of isotope and water quality data to understand groundwater residence time (age), source and flow direction.	Isotope monitoring sites to use as a predictive tool for future water quality and quantity.
Obtain new data	Sites that are currently over-allocated in the Rangitāiki WMA lack further hydrological analyses to set minimum flows apart from the default method.	Consider undertaking detailed IFIM surveys of sites that are heavily over-allocated, OR use EFSAP to help set more defensible low flow levels and allocation levels for over-allocated waterways.
Improvements to methods and reporting	Data quality analysis.	Establish confidence limits and intervals. Maintain gauging programme to ensure that establish regressions are valid. Investigate new methods, including multiple regression; regional prediction curves; and spatial interpolation. Consider synthetic stream flows.
Improvements to methods and reporting	Information on structures in surface water bodies.	Develop a GIS layer that shows the location, size of structure, water volume impounded, available minimum flow downstream, establishment of natural Q_5, MALF or relevant parameter prior to establishment of structure.
Improvements to methods and reporting	Integrated catchment management workgroup–water.	To establish a group of experts to develop and scope work programme that allows groundwater and surface water resources to be managed as a single resource, where hydraulically connected.

Gap theme	Gap	Recommendation
Data for models	Proper assessment as to the accuracy of hydrological models developed by NIWA.	Compare empirically derived flow statistics against flow statistics obtained from hydrological models.
Data for models	Permitted take model.	Maintain and update existing numerical model for calculation of estimated permitted water use for inclusion to water allocation methods. Ground-truth model on five-yearly cycle for WMA.
Data for models	Groundwater flow model.	Develop and calibrate models for groundwater and surface water for the development of an integrated water resource management model.
Data for models	Surface water models for base and low flow.	Construct and calibrate model for surface water allocation.
Data for models	Lack of proper validation of EFSAP model low flows.	Undertake validation of modelled habitat retention obtained through EFSAP to data obtained from a detailed IFIM surveys.
Data management	Lack of regular technical reporting.	Five-yearly technical report, annual summary report, up-to-date data on BOPRC web site (or LAWA).

Part 5: Groundwater

5.1 Introduction

For the Rangitāiki WMA, the spatial extent of the groundwater systems have been 'mapped' using EarthVision, a 3D conceptual model of the geology beneath ground surface. Lithological data from BOPRC Wells database and the Geological and Nuclear Sciences Limited (GNS Science) geological maps were used to construct the spatial model of our groundwater systems. For the Rangitāiki WMA, three groundwater systems have been identified. The groundwater systems are not named; therefore the geological unit that the aquifer occurs in has been used to identify the groundwater systems. These are;

- Tauranga Group sediments (TGS);
- Matahina Formation; and
- Whakamaru Group (Figure 11).

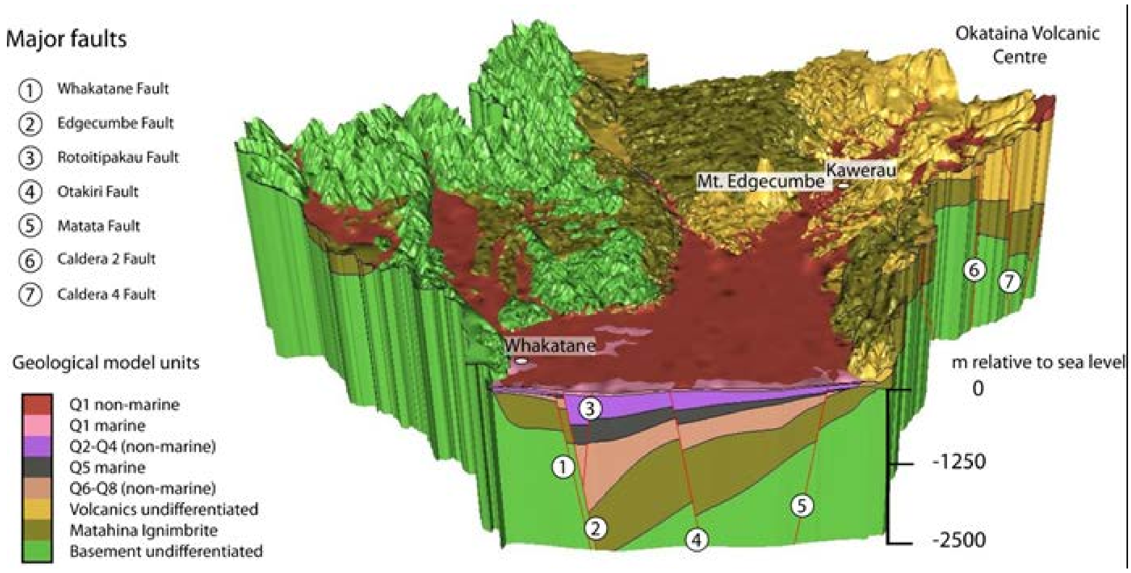


Figure 11 Screen shot of EarthVision 3D model of Rangitāiki WMA (plains), showing the location and extent of the geological units that contain groundwater systems. These extend beneath the Tarawera, Rangitāiki, Whakatāne-Waimana Water Management Areas.

For the TGS, the lithological information and pump test information from groundwater permit applications indicate that the TGS groundwater systems are hydraulically connected to each other and to surface water bodies. This will remain the assertion until future investigations determine otherwise. These types of groundwater systems are known as unconfined or leaky aquifers. However, the lithological and pump test information show that the Matahina Formation is confined, yet is considered unconfined in the GNS model this is a gap in our understanding that needs to be addressed.

The evaluation of the groundwater systems of the Rangitāiki WMA are reported in GNS Science Reports 2010/113 (Rangitāiki Plains) and 2014/283 (Upper Rangitāiki). Report 2010/113, not only considered the spatial extent of the groundwater systems, but also how the systems are replenished, the groundwater flow volume, groundwater quality and allocation. This information was supplied from the NERMN groundwater monitoring programme and allocation information from the Consents database. The GNS reports recommended improvements to our current monitoring programme and identified information gaps that needed to be addressed. These were incorporated into the review of the NERMN groundwater monitoring programme completed in 2013.

In 2013, an assessment of all groundwater monitoring data collected under the NERMN programme was completed and reported in BOPRC Environmental Publication 2013/02. This work assessed the quality of the existing data set and recommendations were made to retain, improve, or drop sites from the programme. The report also identified where new sites were required to provide key information.

5.2 Overview of Current State

The revised groundwater monitoring programme seeks to create a suite of comprehensive monitoring stations at each monitoring site. To consolidate all hydraulic monitoring to one area for co-relation of data (in real-time), ease of access, reduced travel time, shared use of equipment, and efficient operational maintenance.

It was identified that there are two different groundwater areas within the Rangitāiki WMA; the Upper Rangitāiki (above Matahina Dam) and the Rangitāiki Plains area (below the Matahina Dam that includes the plains of the WMA area, Tarawera and Whakatāne-Waimana). For the purpose of this report, these areas will be known as the Upper Rangitāiki WMA (Figure 12) and the Rangitāiki Plains WMA (Figure 13).

The Upper Rangitāiki WMA boundary area (above the Matahina Dam) follows the fault and geomorphology that the groundwater systems are within. This is not the case for the Rangitāiki Plains WMA (below the dam). The groundwater systems of the Upper Rangitāiki WMA are predominantly unconfined, whereas the Rangitāiki Plains WMA has groundwater systems that are confined, as well as unconfined and leaky systems, which are hydraulically connected to surface water.

5.2.1 Upper Rangitāiki WMA

The review of the NERMN programme highlighted a lack of knowledge in the Upper Rangitāiki area regarding location of the groundwater divide between Rerewhakaaitu catchment and Upper Rangitāiki, and the groundwater divide between Hawke’s Bay catchments and the Upper Rangitāiki.

There is also a lack of information about the groundwater contribution to the Rangitāiki River system, and if land use is impacting groundwater quality and in turn increasing nutrient load to the Rangitāiki River system above the Matahina Dam.

A programme of field work was planned and completed in 2014 to provide for the monitoring of rainfall percolation and groundwater levels of the Upper Rangitāiki WMA near the regional boundary with Hawke’s Bay.

BOPRC have a long-term rainfall recorder site, which has been developed into a comprehensive monitoring station with the installation of a lysimeter station, and four groundwater monitoring bores.

The installation of designated monitoring bores was undertaken in conjunction with Hawke's Bay Regional Council, as the location of the groundwater divide ha bearing on the policies and management of nutrient loads in the Hawke's Bay Catchments. The field work is completed and monitoring equipment installed; however the data analysis is yet to be done. This work is to be undertaken in conjunction with Hawke's Bay Regional Council.

The springs in the Upper Rangitāiki WMA are the surface expression of groundwater and recommendations on further work to understand these are given in Part 1: of this report. Groundwater supports the flow of many streams and rivers within the Rangitāiki WMA and this is also considered under Hydrology. Figure 12 and Table 14 summarise the recommendations related to monitoring in the Rangitāiki WMA;

- The blue dots show the location of completed monitoring bores for water level and water quality in the Rangitāiki WMA.
- The blue square shows the location of completed rainfall recharge stations in the Rangitāiki WMA.
- The white circles are areas being investigated for the installation of bore fields (to targeted groundwater systems) and to better understand springs. A rainfall recharge monitoring station is also being investigated for the Rangitāiki Plains. The remaining work programme will progress as finances allow over the next two to three years.

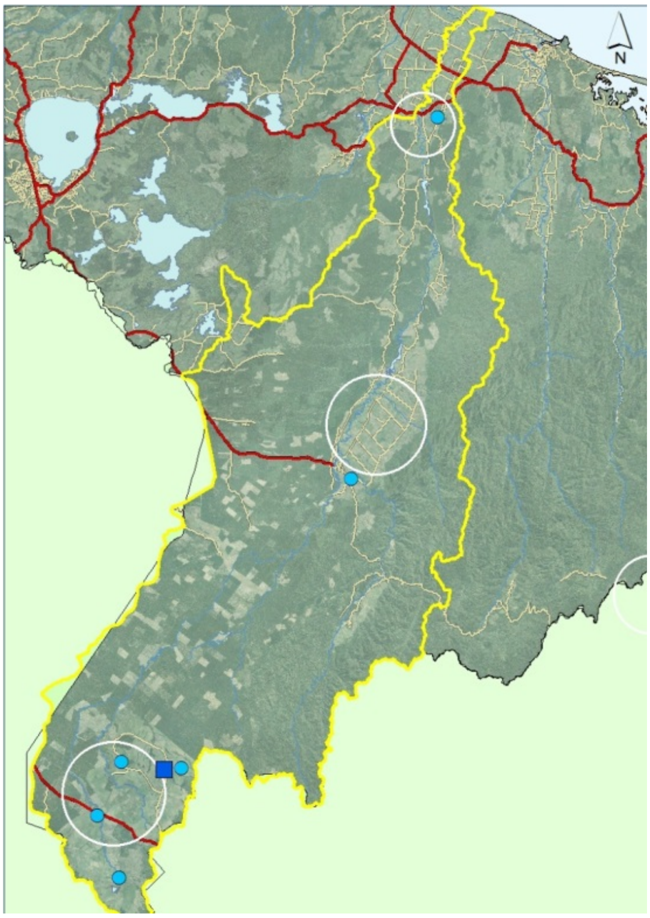


Figure 12 Proposed groundwater monitoring programme for the Rangitāiki WMA.

Table 14 Proposed groundwater monitoring programme for Upper Rangitāiki WMA.

Upper Rangitāiki WMA	Water level	Water quality	Rainfall recharge
Retain existing sites as is	5		1
Upgrade existing sites	1	6	
New installations	2	2	2
Totals	**8**	**8**	**3**

5.2.2 Rangitāiki Plains WMA

The Rangitāiki WMA within the Rangitāiki Plains is a strip out to the coast. The groundwater systems, that the Rangitāiki River contributes to, extend under the Rangitāiki WMA and beneath the Whakatāne-Waimana WMA and Tarawera WMA.

To assess the current state of the Rangitāiki WMA without the inclusion of the Whakatāne-Waimana and Tarawera WMA plains area is problematic in regard to monitoring state of groundwater systems, as these are hydraulically connected. For the purpose of this report and to understanding current state in a common-sense manner, the plains area below the dam is considered as the Rangitāiki Plain WMA and includes the Tarawera, Rangitāiki and Whakatāne River Plain areas (Figure 13).

The NERMN groundwater monitoring programme for the Rangitāiki Plains WMA includes four water level and one water quality bore sites and one spring monitoring site. However, these sites were not based on representative coverage of the aquifer systems being exploited. The monitoring was based on access to privately owned bores, most of which were production bores. This meant that the monitoring coverage was not consistent for each aquifer, and the water level data from production bores was skewed (pumping interference).

The revised groundwater monitoring programme seeks to create a comprehensive monitoring station at each monitoring site. To consolidate all hydraulic monitoring to one area for co-relation of data (in real-time), ease of access, reduced travel time, shared use of equipment, and efficient operational maintenance.

Existing rainfall recorder sites have been investigated to determine whether a rainfall recharge station can be installed to utilise existing access, equipment and data. In the same manner, existing groundwater monitoring sites have been investigated to determine suitability to have a bore field installed to target each groundwater system that lies beneath.

The springs in the Rangitāiki Plains WMA are the surface expression of groundwater and recommendations on further work to understand these are given in Part 1: of this report. Groundwater supports the flow of many streams and rivers within the Rangitāiki Plains WMA and this is also considered under Hydrology.

High groundwater use occurs on the Rangitāiki Plains. These areas are the focus for the Rangitāiki Plains WMA groundwater monitoring programme to assess use and impacts.

The groundwater systems of the Rangitāiki Plains WMA are unconfined, leaky and confined system. The unconfined and leaky groundwater systems are hydraulically connected to each other and surface waters. The confined groundwater systems require further investigation in regard to recharge and sustainable allocation. These groundwater systems extend across the entire Rangitāiki Plains area, including the lower portions of the Tarawera WMA and the Whakatāne-Waimana WMA.

The NERMN 2013 review programme identified several gaps in our monitoring programme. These were the lack of aquifer bore monitoring coverage into high use aquifers, lack of water quality monitoring and spring flows. The recharge mechanisms and volumes to the deeper groundwater systems are not well understood.

Bore 2509 shows a decline in water level over time for the deep confined groundwater system. This indicates more water is being taken from the aquifer than is being recharged to it. Bore 2060 shows a decline in water level over time, for a high use gravel aquifer within the Tauranga Group sediment groundwater system. This system is considered to be unconfined to semi-confined system (leaky).

Due to lack of targeted monitoring bores in crucial locations it is unclear whether the groundwater systems showing decline are localised due high use impacts or extends over the WMA.

Figure 13 summaries the recommendations related to monitoring in the Rangitāiki Plains WMA.

- The blue dots show the location of completed monitoring bores for water level. Water quality monitoring is being investigated for these sites.
- The blue triangle is the only spring monitored for flow and quality.
- The blue square shows the location of a rainfall recharge station to be installed this financial year.
- The white circles are areas being investigated for the installation of bore fields (to targeted groundwater systems) and a spring monitoring programme. The remaining work programme will progress as finances allow over the next two to three years.

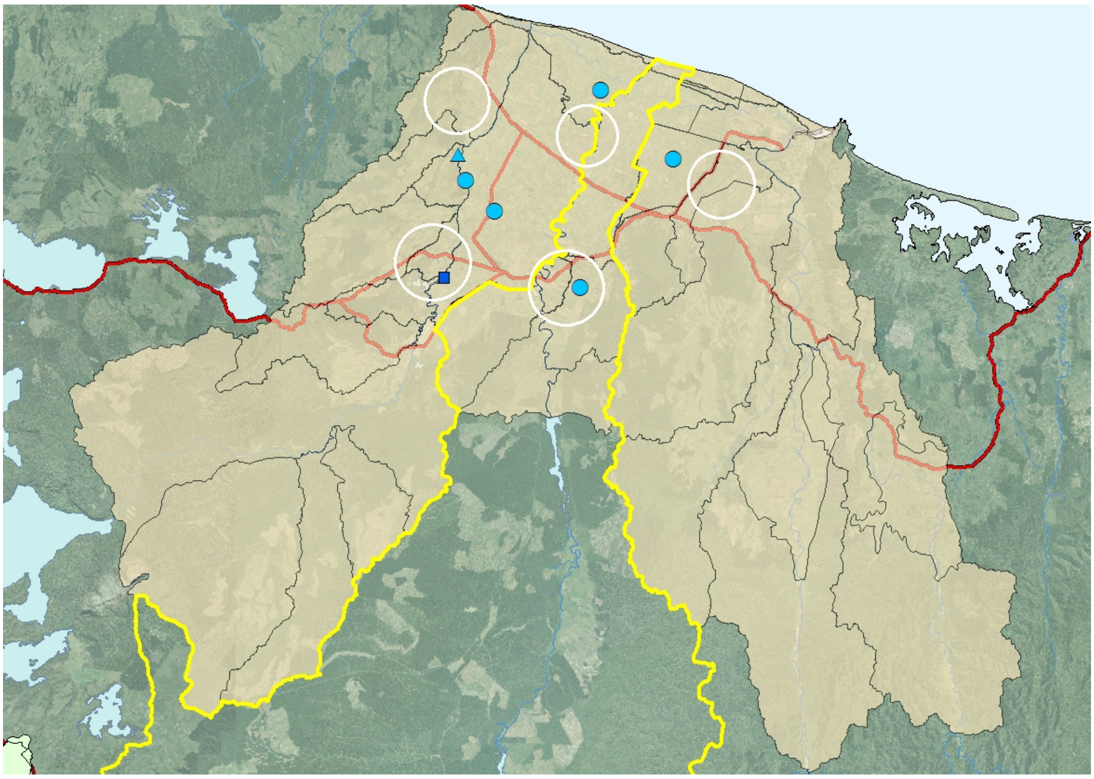


Figure 13 *Spatial area of Tarawera, Rangitāiki, Whakatāne-Waimana WMA plains showing proposed groundwater monitoring programme (Rangitāiki Plains WMA).*

Table 15 *Proposed groundwater monitoring programme for Rangitāiki Plains WMA.*

Upper Rangitāiki WMA	Water level	Water quality	Springs	Rainfall recharge
Retain existing sites as is	5	1	1	1
Upgrade existing sites		4		
New installations	5	5	4	2
Totals	**10**	**10**	**5**	**3**

5.3 Information on Current State

A work programme is planned and underway for the Rangitāiki WMA to address information gaps and improve data. This programme has ten elements; seven monitoring, two models, and one regulatory. The list below summarises the groundwater monitoring programme being implemented and a brief of each work programme for the Rangitāiki WMA:

(1) Bore fields (level and quality - automated continuous data; aquifer testing).

(2) Bore log and core samples (informs model).

(3) Rainfall recharge (recharge zones).

(4) Isotope.

(5) Spring (surface expression of groundwater).

(6) Groundwater-surface water interaction (as one resource).

(7) Groundwater flow model (MODFLOW & ArcGIS).

(8) EarthVision Model update.

(9) Resource Management Act consented and permitted takes (allocation).

5.3.1 Bore field (partial information gap being addressed)

Where possible monitoring sites will be consolidated into bore fields. This will be a monitoring station where a number of bores are installed to target depths (aquifers) for regular water level and quality sampling. These stations may also include rainfall recorders, lysimeters, soil moisture probes, and where appropriate, hydrological sites. These comprehensive monitoring sites aim to be automated as much as possible for real-time data assessment and resource management.

Aquifer testing is required to determine hydraulic conductance and connectivity within aquifers, between unconfined, semi-confined aquifers, and also between aquifers and surface water bodies. The current default is to use pump test data from groundwater permit applications.

5.3.2 Bore log and core samples (partial information gap being addressed)

A programme of drilling is planned and being undertaken to establish designated monitoring bores to target aquifers. This will provide adequate coverage for resource management. The lithology is being recorded and samples taken for analysis. These samples are examined to determine the geological unit being drilled through. This provides robust data for the conceptual geological models. Each aquifer is being hydraulically tested, samples for water quality analysis taken, and isotope work completed to provide robust data on aquifer properties for the groundwater flow models planned for development. Four bores have been installed in the Upper Rangitāiki for this purpose.

5.3.3 Rainfall recharge (gap being addressed)

It was identified that rainfall and rainfall infiltration rates to storage are crucial to the water balance calculation. Infiltration data can be used to calculate groundwater flows and manage allocation. One rainfall recharge site was installed and monitoring equipment completed in March 2015. Another is planned for installation in April 2015. This data will help inform the groundwater flow model for the Rangitāiki WMA.

The lysimeter sites are located under pastoral land use (not irrigated). The infiltration to storage beneath other land use has not been considered. This would be relevant for understanding recharge rates under different land uses in the WMA; exotic forest, native forest, horticulture and irrigated sites. This may also provide information on nutrient loss.

5.3.4 Isotope (partial information gap)

The monitoring of isotopes has not been part of the NERMN monitoring programme. Work has been completed for some groundwater systems under the BOPRC drill programme, by District Councils, and GNS Science for research purposes. The value of isotope analysis is that the data can provide crucial information about residence time, flow direction, source of recharge and groundwater flow. It supports work to determine groundwater flow to surface water bodies within the Rangitāiki WMA, and can provide a unique signature to identify the aquifer.

5.3.5 Spring (gap not yet addressed)

Springs are the surface expression of groundwater. The quantity and quality of spring flows has not been part of the NERMN monitoring programme (with the exception of Braemar Springs). To determine groundwater available for allocation, data is required on the volumes of groundwater that leave the system to provide spring flow to surface water bodies. The flow needed to support surface water values can then be accounted for when setting allocation limits for the groundwater systems. To determine these flows and manage allocation of the groundwater resource requires that springs be part of our regular monitoring programme. This data (flow, quality and isotopes) will also support allocation from surface waters in relation to the Q_5, MALF and IMFR.

5.3.6 Groundwater – surface water interaction (gap not yet addressed)

Within the Rangitāiki WMA are unconfined; semi-confined (leaky) groundwater systems that are hydraulically connected to surface water. Many of the spring fed rivers and streams within this WMA are sourced from groundwater. Along the length of a stream, from hill country to the coast, water can flow into and out-of the stream system from groundwater; groundwater feeds to surface water systems (springs, streams, rivers and wetlands) in some areas, and surface water feeds the unconfined groundwater systems in other areas.

There are currently no monitoring regimes to measure and understand this interaction. This interaction becomes important when needing to manage water resources and set allocation limits for both surface water and groundwater. Water allocation from groundwater systems has the potential to impact on spring flows and affect in-stream flow requirements for a number of streams in the Rangitāiki WMA.

New NERMN programmes established under the Surface Water Quantity and Quality programmes will be of relevance to the understanding of groundwater-surface water interaction for the purpose of allocation.

5.3.7 Groundwater flow model (gap being addressed)

The proposal for development of a groundwater flow model for the Rangitāiki WMA has been funded. The aim of the model is to provide groundwater flow, groundwater-surface water interaction, and water allocation scenarios to predict long-term sustainable management of the water resource. This model construct has been planned for future use in an integrated catchment model.

5.3.8 EarthVision model - update (gap being addressed)

The conceptual models of the geology (groundwater systems) were constructed during 2010 and 2014 for the Rangitāiki Plains and Upper Rangitāiki respectively. Since this time improvements to data entry and quality checks, additional bore information, updates to Digital Terrain Mapping, and updates to national geological mapping in New Zealand, has meant that valuable information is not included. To address this, a proposal is being prepared for the ongoing update and maintenance of these models so that the information and model remain relevant.

5.3.9 Resource Management Act consented and permitted takes - allocation impact (gap being addressed)

Rangitāiki WMA has been identified as a priority area. One reason for this is that the groundwater evaluation reports completed by GNS provided estimated groundwater volumes for the groundwater systems within the Rangitāiki WMA. In the absence of groundwater allocation policy in the Regional Water and Land Plan, the default allocation regime is the Proposed National Environmental standard on ecological flows and water levels. Estimated actual consented use, calculated estimated groundwater flow, and default allocation limit flagged this area as having allocation concerns. Allocation pressure needed to be investigated further and a better understanding of how the groundwater systems responded over time.

Part of the allocation calculation necessarily includes estimates of water use covered by permitted activities under the RMA and WLP. A numerical model has been constructed to provide estimated volumes and field work undertaken to 'ground-truth' the model. The results from this model will form part of the over-all water use budget and allocation for the Rangitāiki WMA.

5.4 Gaps and recommendations

Recommendations to improve the data record and knowledge of the Rangitāiki WMA water resources have been briefly described in section 5.3. These recommendations have been listed in (Table 16) and further set out in the Current State Project Gap Identification and Prioritisation Template spreadsheet attached.

Table 16 Recommended solutions to address gaps in current knowledge.

Gap theme	Gap	Recommendation
Data for models	Inadequate coverage of data for comparison of water resource monitoring data.	Expand the geological portion of the REC to include more classes.
Data for models	Improve conceptual understanding of subsurface geology.	Designated bore fields to target depths. Record lithology and obtain cores for geological unit identification.
Obtain new data	Lack of monitoring sites within geological provenances	Target groundwater systems (aquifers) by installation of bore fields, for comprehensive monitoring and data comparison. This includes groundwater – surface water interaction.
Obtain new data	Contribution of groundwater (quality and quantity) to waterways.	Investigate the contribution of groundwater to waterways (springs, base-flow to rivers and wetlands) within the Rangitāiki WMA and the relative nutrient load contributed from groundwater sources.
Data for models	Lack of information on hydraulic conductance within aquifers, between unconfined, semi-confined aquifers, and also between aquifers and surface water.	Hydraulic pump testing of the aquifer systems within the Rangitāiki WMA and surface water bodies.

Gap theme	Gap	Recommendation
Obtain new data	Need for improved understanding of infiltration rates to subsurface storage.	Maintain and monitor existing sites until robust statistical relationships have been developed. Install new sites to obtain adequate coverage.
Obtain new data	Risk of salt water contamination to fresh groundwater resources.	Maintain and monitor existing sites to understand movement of fresh water – salt water interface with pumping stress over time. Establish new sites if necessary to address risk.
Obtain new data	Lack of isotope and water quality data to understand groundwater residence time (age), source and flow direction.	Isotope monitoring sites to use as a predictive tool for future water quality and quantity.
Improvements to methods and reporting	Integrated catchment management workgroup –water.	To establish a group of experts to develop and scope work programme that allows groundwater and surface water resources to be managed as a single resource, where hydraulically connected.
Improvements to methods and reporting	Frequency and interval of monitoring to establish trends for both quality and quantity.	Standardise monitoring timeframes to provide data that can be assessed over time for trend analysis. Increase use of automated continuous monitoring sites for water level data over time. For water quality increase the frequency and establish regular sampling intervals, to allow for trend analysis over time (seasonal change).
Data for models	Permitted take model.	Maintain and update existing numerical model for calculation of estimated permitted water use, for inclusion to water allocation methods. Ground-truth model on five yearly cycle for WMA.
Data for models	Conceptual groundwater model.	Maintain and update existing conceptual groundwater models from Wells database, updated DTM and geological maps.
Data for models	Groundwater flow model.	Develop and calibrate models for groundwater and surface water for the development of an integrated water resource management model.
Data management	Lack of regular technical reporting.	Five-yearly technical report, annual summary report, up-to-date data on BOPRC web site (or LAWA).

Part 6: Freshwater quality – rivers and streams

6.1 Introduction

River water quality in this section refers to the physical and chemical properties of flowing freshwater (e.g. temperature, dissolved oxygen, water clarity). The indicator bacteria *E.coli* is also included as an indicator of bacterial contamination in the waterway. Periphyton and cyanobacteria are covered in Parts 8 and 9 in this report.

Water quality is impacted by many natural factors (e.g. climate, geology) and anthropogenic factors (e.g. land-use change, point-source discharges). Water quality in a river or stream can impact its ability to support healthy aquatic ecosystems and protect or provide for desired values. For example, increased sediment in a waterway could reduce a river's aesthetic and recreational appeal as it would look brown or dirty. Increased sediment may also make substrate conditions in the river unsuitable for many invertebrate taxa, and for many fish species that require clean gravels for spawning.

BOPRC monitors a number of water quality parameters. These include some that are compulsory national attributes in the NPS-FW and some that are not. All are reported here as it is possible that some of the parameters will be assigned as attributes in the future. Note also that some future attributes may not be monitored at all (e.g. urban contaminants). This report does not assess which attributes would be most appropriate to support the range of values associated with the Rangitaiki WMA.

6.2 Information reviewed

Currently, nine sites within the Rangitāiki WMA are sampled as part of the NERMN programme. There are two NERMN modules relevant to this review: river water quality sampling and recreational bathing sampling. The current sites and sampling details are provided in (Table 17) for both the river and recreational bathing programmes. The sites are as follows:

- Two sites on a rotation sampling programme whereby monthly sampling is undertaken for a year, once in every three years since 2003,
- Two sites monitored quarterly since 2010,
- Three sites operated by NIWA as part of the National River Water Quality Monitoring Network, these are sampled monthly since 1989, and
- Two sampled weekly/bi-weekly over summer each year since 2003 (one site) or 2004 (one site). Note: two additional sites have historic *E.coli* data (see Table 17).
- Five historic sites that are no longer currently monitored.

Table 17 *NERMN river monitoring sites, parameters monitored, sampling frequency and length of data record within the Rangitāiki WMA. Grey boxes indicate sites in the NERMN Rivers programme, yellow boxes are sites in the NERMN recreational bathing programme. Sites in italics are NIWA sites.*

NERMN site name	**Site ID**	**Parameters monitored**	**Sampling frequency**	**Data record**	**River flow**
Rangitāiki at inlet to Aniwhenua Canal	BOP110016	Temperature, dissolved oxygen, pH, water clarity, conductivity, NH_4-N, NO_x-N, TN, DRP, TP, turbidity, TSS, colour coefficient, *E.coli*, Faecal Coliforms, *Enterococci*	Quarterly 1991-1998 Monthly on 3 year rotation 2003-present	1991-present	Yes#
Rangitāiki at Matahina Dam	BOP110082		Monthly on 3 year rotation	2003-present	Yes*
Otamatea at end of Road	BOP110000		Quarterly	2010-present	Yes^
Rangitāiki at SH 5 Bridge	BOP100104		2-4 times per year from 1999-2001 Monthly Jul 2004-Jun 2005 Quarterly since 2010	1999-present	No+
Rangitāiki at Waiohau Bridge	BOP110117	Temperature, dissolved oxygen, turbidity, colour coefficient, pH, DRO, NH4N, NO3, TKN, TP, *E.coli*, enterococci, faecal coliforms	3-4 times per year from 1985-1987 and 1991-1995 Daily July 1998 (Flow, SS and turbidity only)	1985-1998	July 1998 only
Rangitāiki River at Kopuriki (Rabbit Bridge)	BOP110081	SS, DRP, NH4N, NNN, TP Also DO (Dissolved Oxygen) and temperature 1995-87	2-4 times per year from 1985-1987 and 1993-1995	1985-1995	No
Rangitāiki River upstream of Horomanga confluence	BOP210113	Temperature, SS, DRP, NH4N, NNN, TKN, TP, chlorophyll-a	Annual 1995-1996	1995-1996	No
Rangitāiki River downstream of Whirinaki confluence	BOP210114		Annual 1995-1996	1995-1996	No

NERMN site name	**Site ID**	**Parameters monitored**	**Sampling frequency**	**Data record**	**River flow**
Whirinaki at Galatea Rd Bridge	*BOP110014*	*Temperature, dissolved oxygen, pH, conductivity, NH_4-N, NO_x-N, TN, DRP, TP, turbidity.* *E.coli, Faecal Coliforms, Enterococci 2001-2008, 2011-current*	*Monthly*	*1989-present*	*Yes**
Rangitāiki at Old Murupara Bridge	*BOP110015*		*Monthly*	*1989-present*	*Yes**
Rangitāiki at Te Teko Bridge	*BOP110018*		*Monthly*	*1989-present*	*Yes**
Rangitāiki River above Raft Exit	BOP160107	*E.coli*	Sporadic 1998-2004	1998-2004	N/A
Rangitāiki at Te Teko Bridge	BOP110018	*E.coli*	Weekly over summer	2004-present	N/A
Rangitāiki River at Edgecumbe	BOP160108	*E.coli*	Sporadic 1998-2004	1995-2000	N/A
Rangitāiki River at Thornton Domain	BOP160109	*E.coli*	Weekly/biweekly over summer	2003-present	N/A

derived from NIWA flow recording station nearby
* rated sites
^ manual flow gauging at time of sampling
+ some manual gaugings have been historically carried out, however this only covers approximately 50% of sampling occasions

Comparison of NERMN river sampling sites with their corresponding REC class (Table 18) shows that there is good representation of dominant climate classes, slight under-representation of lowland elevation source of flow, and over-representation of hill source of flow. In terms of geological representation, all water quality sites are classified volcanic acidic, slightly over-representing this category and under-representing hard sedimentary classification. Similarly, there is a slight over-representation of streams dominated by pastoral and exotic forestry land use, and an under-representation of streams draining indigenous forestry. Finally, the majority of the water quality sampling sites are from large streams (order >5), with small and medium order streams under-represented.

Note that the sampling design behind the current NERMN sites was focused on identifying trends and spatial patterns in large rivers such as the Rangitāiki (an important river for the public) rather than representing all waterways within this WMA. This analysis simply highlights that the new requirements of the NPS-FW will require more monitoring on waterways that were not considered under the original aims of the NERMN programme.

Table 18 Calculated percentage stream length in different REC classes for climate, source of flow, geology, land cover and stream size within the Rangitāiki WMA, and number and percentage of NERMN water quality monitoring sites in each class. NOTE: This assessment included the four water quality sites currently monitored under the NERMN rivers programme, and the three NIWA sites.

Variable	Value	% of WMA stream length	No. WQ Sites	% WQ Sites
Climate class	Cool-dry	0.1	0	0
	Cool-wet	85.7	6	85.7
	Warm-dry	1.5	0	0
	Warm-wet	12.7	1	14.3
Source of flow	Hill	77.5	6	85.7
	Lowland	21.6	1	14.3
	Lake	0.7	0	0
	Mountain	0.2	0	0
Geology	Alluvium	0.2	0	0
	Hard sedimentary	6.2	0	0
	Miscellaneous	0.0	0	0
	Volcanic acidic	93.6	7	100
Land cover	Exotic forestry	50.9	4	57.1
	Indigenous forestry	26.3	1	14.3
	Pastoral	20.9	2	28.6
	Scrub	1.0	0	0
	Tussock	0.8	0	0
	Urban	0.1	0	0
Stream size	Small (Order 1+2)	73.1	2	28.6
	Medium (Order 3+4)	20.9	0	0.00
	Large (Order 5+)	6.0	5	71.4

In addition to NERMN sampling, there have been numerous surveys on water quality within the Rangitāiki WMA. The following reports are particularly relevant:

- **An ecological assessment of waterways throughout the Rangitaiki Catchment (Suren, 2014).**

This project identified current gaps in ecological monitoring and undertook a comprehensive ecological survey to fill those gaps. This included taking spot water quality samples, and flow measurement at sites where invertebrate sampling was undertaken (95 sites). Following this initial investigation, 28 sites (mainly smaller tributary streams) were selected for ongoing monthly monitoring for four to six months (timeframe determined by available resources). Samples were analysed for nutrients (nitrogen and phosphorus) and bacteria (*E.coli*). Samples were also taken from Lakes Matahina and Aniwaniwa to calculate the Trophic Level Index (TLI). Key water quality recommendations from the Suren (2014) report included:

  - Continue with water quality monitoring.
  - Monitor algal cover and/or biomass and develop nutrient limits if nutrients are causing algal blooms.
  - Continue monthly sampling at the lakes (Aniwaniwa and Matahina).

- **Assessment of the state of the Rangitāiki River within the Ngāti Manawa rohe (Boubee et al. 2009).**

This comprehensive assessment investigated water quality (along with other parameters) in the Rangitāiki River Catchment upstream of Lake Aniwaniwa. In addition to reviewing water quality data from NIWA and BOPRC, the study conducted single samples at 16 sites on 28-29 April 2009. These samples were analysed for nutrients, bacterial contamination and physical properties (e.g. clarity, DO, temperature).

- **Ecological Surveys of sections of the Rangitāiki and Wheao Rivers (Bioresearchers, 1985a, 1986a, 1986b, 1987, 1988, 1989).**

These ecological surveys were conducted as part of the conditions of a water right for the Rangitāiki-Wheao Hydroelectric Development Scheme. Spot water quality measurements were made at four to six sites (two to three sites on each of the Wheao and Rangitāiki Rivers) alongside fish (trout), invertebrate and wildfowl surveys.

- **A survey of a section of the Rangitāiki River (Bioresearchers, 1978, 1979, 1980, 1985b).**

These surveys were conducted along approximately 10 km of the Rangitāiki River near Edgecumbe, to determine the impact of discharge from the Rangitāiki Plains Dairy Company dairy factory at Edgecumbe. Five sites were sampled for physical parameters (e.g. temperature, dissolved oxygen, conductivity, and pH), chemical parameters (e.g. suspended solids, turbidity, nutrients) and biological parameters (e.g. faecal coliforms).

- **Ecological monitoring surveys of the Bay of Plenty (Bioresearchers, 1974, 1975a, 1975b).**

These surveys sampled water quality and ecology at three sites along the Rangitāiki River.

- **Ecological Survey of the Lower Rangitāiki River (Kingett Mitchell, 2001).**

This survey was conducted to assess the impact of changing the peak discharge regime from single daily to two-peak daily from the Matahina Dam. The survey sampled three sites on the Rangitāiki River between Matahina Dam and approximately 3.5 km below the Edgecumbe township. A control site was selected on the Tarawera River as a comparison. Samples were analysed for physical properties (e.g. temperature, conductivity, dissolved oxygen, pH and water clarity), and nutrients.

- **Lower Rangitāiki River Surveys (McIntosh, 1986).**

This survey sampled water quality at six sites on the Rangitāiki River between Thornton Domain and 0.5 km upstream of Edgecumbe. The samples were analysed for physical parameters (e.g. temperature, dissolved oxygen) and chemical parameters (e.g. nutrients and suspended solids). The purpose of the survey was to identify the amount of sewage fungus in the Rangitāiki River.

The Ministry for the Environment (MfE) commissioned an extensive review of freshwater monitoring protocols and reporting nationally as part of the New Start for Fresh Water programme (Davies-Colley et al. 2012). The outcomes of the review have been the development of recommended variables and sampling regimes to provide national consistency for state of environment water quality monitoring. The key water quality recommendations from the report were:

- Sampling should be monthly, within ± 1 hour of previous sampling events and occur in all flow and weather conditions (where practicable and safe to do so).
- All sites should have corresponding stream flow available that corresponds to sampling events.
- Visual clarity should be measured on each sampling occasion, with alternative methods used during high-flow conditions (see Davies-Colley et al. 2012 for details).
- Consistent field protocols be used (preferably nationally agreed protocols).
- Reliable and accurate site metadata to be recorded.

There have also been three reviews of BOPRC monitoring programmes relevant to this report.

- **Review of BOPRC Natural Environment Regional Monitoring Network freshwater quality (Hamill, 2012).**

This project reviewed freshwater quality NERMN monitoring programmes and evaluated their effectiveness for spatial representativeness, QA/QC protocols and the adequacy of variables/frequency for meeting the Council's functions under the RMA. Key recommendations from the Hamill report included:

  - Increase the number of NERMN river sites in hill fed streams draining non-volcanic geology, and low-elevation streams draining non-volcanic geology.
  - Monitor all NERMN sites monthly and phase out rotation sampling.
  - Include possible reference sites in the network.
  - Increase the number of sites with permanent DO loggers, particularly in large U-shaped rivers.
  - Monitor periphyton cover and/or biomass at appropriate sites, and store data using a single taxonomic list.
  - Include duplicates/blanks as part of QA/QC protocols.
  - Laboratory data entered to the best available estimate (i.e. not censored).
  - Improve the monitoring and reporting of consents and land use intensity to enable easy integration with NERMN monitoring and assist with trend interpretation.
  - Re-survey wetland extent, and initiate wetland condition monitoring.

- **Low flow monitoring Strategic Review (Ellery and Putt, 2012: Internal Report).**

This reviewed the hydrologic monitoring network in relation to its effectiveness to provide adequate regional representation for the management of low-flows. Many recommended enhancements to the current network were proposed. There were no recommendations for alterations in the Rangitāiki WMA, this was largely as a result of the fact that the area was not a pressure area for surface water allocation at the time of completing the report. A thorough hydrological review has since been completed for the Bay of Plenty region (Fernandes, 2015). Relevant recommendations from the Fernandes report have been incorporated in Part 9 of this report.

- **Review of the NERMN Programme 2014 (Donald, 2014).**

This reviewed the entire NERMN monitoring programme and made recommendations for enhancement. The recommendations align with those reported in Hamill (2012) and Davies-Colley et al. (2012) and included:

    - Increase the number of network sites by 10 (including one to two reference sites and sites meeting the non-volcanic and hill or low-elevation fed classes).
    - Increase sampling to monthly for all sites.
    - Have flow or stage height recorded at each sampling event.

6.3 Current water quality state in the Rangitāiki WMA

The following summarises the current state of the waterways based on the best available information. To gain an understanding of the current state of waterways within the Rangitāiki WMA, water quality data for NERMN sites has been assessed against the National Objectives Framework (NOF). The NOF outlines a series of state ‘bands’ and a minimum acceptable state (national bottom line) for the following attributes in rivers:

• Periphyton	To protect ecosystem health
• Nitrate	
• Ammonia	
• Dissolved Oxygen	
• *E.coli*	To protect human health for recreation
• Cyanobacteria	

Figure 14 shows the NOF bands within the Rangitāiki WMA respectively. All seven NERMN sites were graded ‘A’ band for ammonia, and six out of the seven sites were graded ‘A’ band for nitrate, with one site on the Otamatea River being graded ‘B’ band. The ‘A’ band is designed to protect 99% of species, and the ‘B’ band 95% of species. In the ‘B’ band, ammonia toxicity starts to impact on 5% of the most sensitive species in a waterway (NPS, 2014). Review of previous years’ monitoring for Rangitāiki at Matahina Dam and Rangitāiki at Aniwhenua Canal show that these sites consistently fall within ‘A’ Band for both nitrate and ammonia (Scholes, 2015).

The NOF outlines two levels of protection for human health based on the indicator bacteria *Escherichia coli (E. coli)*. These levels are based on the level of immersion in water, and relate to the risk of exposure to faecal contamination. Primary contact refers to activities that involve full immersion in water, like swimming. Secondary contact refers to activities like wading and boating that involve occasional immersion in water, and the possibility of ingesting water. The Rangitāiki at Murupara Bridge is the only site graded in ‘A’ Band for primary contact (swimming), which is deemed to have a ‘low risk’ of infection from swimming (up to 1% risk; NPS, 2014). The Whirinaki River at Galatea Bridge and the Rangitāiki River at both SH 5 and Te Teko are all graded ‘B’ band, which is deemed to have a ‘moderate risk’ of infection from swimming (up to 5% risk). The bottom end of the ‘B’ band also represents the minimum acceptable state for swimming. The Rangitāiki River at Aniwhenua Canal, Matahina Dam, and the Otamatea River sites have *E. coli* levels that are greater than the minimum acceptable state for swimming.

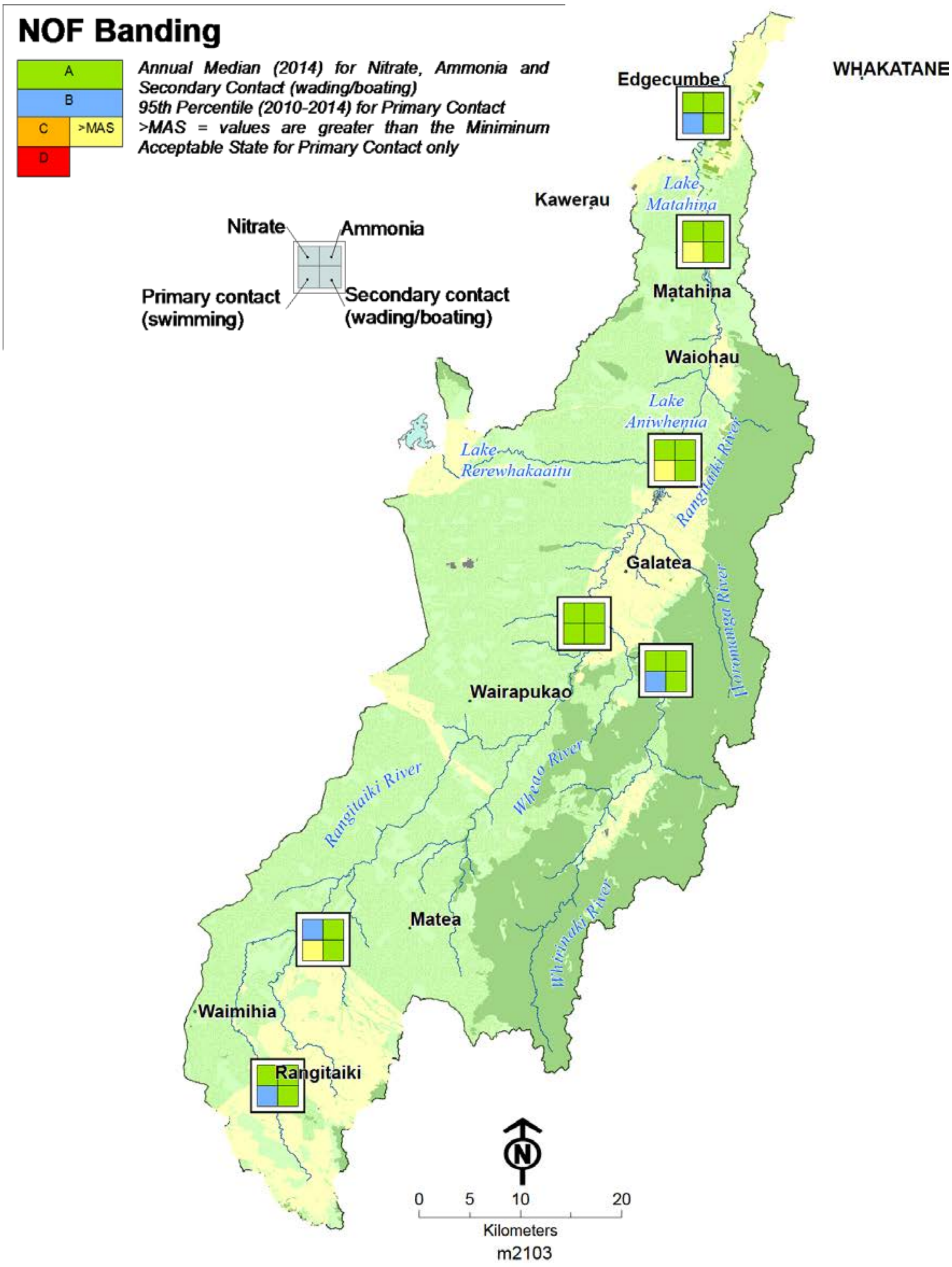


Figure 14 NOF Banding within the Rangitāiki WMA.

A similar picture exists when reviewing the summer surveillance of recreational bathing sites (refer Table 19). Rangitāiki River at Thornton Domain is graded in 'A' band for both primary and secondary contact, and Rangitāiki River at Te Teko is graded 'B' for primary contact and 'A' for secondary contact (Scholes, 2015).

Table 19 NOF Banding for Human Health for primary contact recreation (E.coli 95th percentile 2009-2014) and secondary contact recreation (annual median 2013-2014).

Site	**NOF 1º (swimming)**	**NOF 2º (wading/boating)**
Rangitāiki River at Thornton Domain	A	A
Rangitāiki River at Te Teko	B	A

Routine periphyton monitoring has not been established in the Bay of Plenty region, and this is a knowledge gap that is currently being addressed (see Part 7: This is important as the NOF nitrate bands are based on toxic effects, and the fact that the A band is achieved at a particular site does not necessarily rule out the possibility that nitrate is an issue for periphyton, and results in unacceptably high periphyton biomass. Additionally, continuous dissolved oxygen is currently only monitored at one site on the Tarawera River (outside the Rangitāiki WMA).

6.4 Water quality trends

Whilst current state gives an indication of the state of waterways, trends indicate whether or not a particular parameter (e.g. water clarity, *E.coli*) is getting better or worse over time. Table 20 shows the 10 year water quality trends for the key attributes in the NOF (Scholes, 2015).

Table 20 Trends in water quality parameters. ▲= Declining water quality, ▼ Improving water quality, NT = No trend, N/A = insufficient data (Scholes, 2015).

Site	**Nitrate**	**Ammonia**	***E.coli***
Rangitāiki at Inlet to Aniwhenua Canal	NT	NT	NT
Rangitāiki at Matahina Dam	NT	NT	NT
Otamatea at end of Road	N/A	N/A	N/A
Rangitāiki at SH5 Bridge	N/A	N/A	N/A
*Whirinaki At Galatea Rd Bridge**	▼	NT	NT
*Rangitāiki at Old Murupara Bridge**	▲	NT	NT
*Rangitāiki at Te Teko Bridge**	NT	NT	NT

* NIWA sites

6.5 Gaps and recommendations

There are many factors, both natural and human induced, that impact on water quality and all need to be considered in the discussion of setting water quality limits. For example, consideration needs to be given (but not restricted to) the following:

- Existing water quality (Policy CA3 in NPS-FW).
- Connection between water bodies (Policy B1 b).

- Sensitivity of, and connectivity with, downstream receiving waters (e.g. lakes) (Policy A1 a ii and iii in NPS-FW).
- Natural geological conditions and background levels of contaminants.
- Climate (Policy B1 a in NPS-FW).
- Minimum flows and flood frequency.
- Interaction between groundwater and surface water (Policy B1 b in NPS-FW).

In considering these factors and incorporating the information reviewed above, gaps have been identified that range from improving current methodologies, to establishing new monitoring programmes.

6.5.1 Obtain new data

There are a number of knowledge gaps identified that require gathering new data. For example, continuous dissolved oxygen (DO) is currently only monitored within the region at one site on the Tarawera River (outside the Rangitāiki WMA), and this knowledge gap has been included in Table 21 below. Dissolved oxygen is a measure of how much oxygen is dissolved in the water. Stream ecosystems both produce and use oxygen. Oxygen is provided to streams from the air, and also from aquatic plants as a by-product of photosynthesis. Conversely, oxygen is consumed within a stream by aquatic animals as they respire, and as organic matter (e.g. leaves, twigs) decompose. Additionally, waste that is discharged into a river (e.g. from industry or stormwater) can also contain contaminants that consume oxygen. Oxygen is needed in aquatic ecosystems to support life. Subsequently, the NOF requires that DO be measured downstream of point-source discharges and this is to protect the value of ecosystem health.

There are currently two significant point source discharges within the Rangitāiki WMA, one at Murupara and one at Edgecumbe. Dissolved oxygen should be monitored downstream of both of these discharges in accordance with the time periods outlined in the NOF.

Many streams within the Rangitāiki WMA are fed by groundwater discharging as springs into the waterways. The contribution of groundwater to the flow of the rivers is, as yet, unquantified. Similarly, the impact of this contribution to water quality is also unknown. Work is currently being proposed to address this gap (see Part 5). Similarly, other gaps identified included the hydrologic links and impacts of waterways with wetlands and the drainage network within the WMA.

6.5.2 Spatial frameworks

Part 2 outlined the overall spatial considerations for implementing the NPS-FW. Building on that discussion, a decision needs to be made on the scale at which freshwater will be managed, monitored and accounted for under the NPSFW. For example, there are 4,402 km of waterways within the Rangitāiki WMA, are the same water quality limits going to be set for every waterway within the WMA (i.e. at a WMA level)? Or are limits going to be set at sub-catchment level? Decision needs to be made on the spatial scale before values and numeric limits for water quality attributes can be set.

6.5.3 Improvements to methods and reporting

A number of gaps identified are able to be filled by improving methodologies to bring them in line with current best-practice. For example, changing sampling frequency from quarterly or rotational sampling, to monthly sampling each year, enables trends to be detected over time once sufficient data has been collected. Additionally, having flow recorded for each monthly sampling event allows relationships between flow and contaminants to be built up over time, allows trend data to be corrected for flow, and allows computation of catchment load.

6.5.4 Data management

Similarly, with some improvements to data management practices, some gaps could be partially filled. For example, there is a large amount of water quality data in reports prepared as part of consent applications, this information could be better captured in a database (with appropriate quality coding and reference) and would increase the amount of information available for water quality assessments.

6.5.5 Data for models

It is acknowledged here that models can be a useful tool in analysing changes within a catchment (e.g. the change in downstream nutrient levels if nutrient discharge from a sub-catchment is changed) and this is beneficial when trying to set limits to meet desired values. It is thus recommended that opportunities for model development or modification of existing models be considered for the Rangitāiki WMA.

Table 21 summarises the gaps identified based on the information reviewed above and gives recommendations on how each gap could be addressed. Wherever possible, these recommendations should be addressed alongside recommendations for other environmental components (e.g. invertebrates, fish, hydrology, soils and groundwater) as these components are all connected within the environment and this is supported by Objective and Policy C1 in the NPS-FW.

It should be noted that other gaps are likely to become apparent as implementation of the NPS-FW proceeds and this list will need to be amended accordingly.

Table 21 Identified gaps for water quality sampling and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Improvements to methods and reporting	Monthly water quality sampling (± 1hr) every year.	Increase the frequency of sampling at four existing sites to monthly every year. Support: Donald (2014), Hamill (2012), Davies-Colley et al. (2012)
Improvements to methods and reporting	Flow recorded for each sampling event.	Measure flow or record stage height (to read flow of existing rating curve) on each sampling occasion for all new sampling sites established, and all current sites. Support: Donald (2014), Davies-Colley et al. (2012)

Gap theme	Gap	Recommendation
Data management	Information from consents, compliance and land management be integrated (where applicable) with NERMN data and interpretation.	Ecological or monitoring reports for consents be registered individually in Objective (i.e. not just under consent file). Water quality data from these reports should be captured in existing spreadsheets/databases (see recommendation below). Information on land management activities (i.e. fencing of waterways, farm/nutrient management plans) be grouped for each WMA and this information able to be queried/extracted as needed for purposes of interpretation of water quality data. Support: Hamill (2012)
Data management	Easy access to water quality from other sources (e.g. historic sampling, data from consents etc.)	Investigate options to capture, store and maintain a portal to house all water quality data (regardless of source), with appropriate reference and quality coding.
Improvements to methods and reporting	Uncensored laboratory data.	Enter data to best estimate with appropriate coding to indicate level of accuracy. Support: Hamill (2012)
Improvements to methods and reporting	Sample blanks and duplicates as part of QA/QC protocols.	Incorporate this process as part of standard NERMN sampling. Support: Hamill (2012)
Obtain new data	Lack of DO profiles, especially in U-shaped streams. AND Lack of DO monitoring downstream of point source discharges.	Install DO loggers downstream of point source discharges at Edgecumbe and Murupara. Loggers should remain in place from 1 November to 30 April to permit comparison against NOF bands. Support: Hamill (2012), Davies-Colley et al. (2012).
Obtain new data	Under-representation of dominant stream classes in the region (based on REC).	Add 10 new permanent monitoring sites to the NERMN Rivers network to better represent dominant waterways in the Bay of Plenty. Support: Hamill (2012), Donald, (2014)
Improvements to methods and reporting	Consistent and regular visual clarity sampling.	Visual clarity should be measured on each sampling event irrespective of stream flow. Alternate methods to be used during periods of high flow. Support: Davies-Colley et al. (2012)
Obtain new data	Underrepresentation of streams draining indigenous forestry and hard sedimentary geology and lowland fed streams. AND Lack of representation of tributaries draining into main stem rivers.	Initiate new water quality sampling sites (approximately 10 sites). The location of these sites should coincide with sites selected for water level/flow monitoring (see Part 9), periphyton monitoring (see Part 6), and align with sites monitored as part of ecological assessment (Suren, 2014). This could be an opportunity for sentinel sites (see Part 12). Monitor sites initially for one year and review data to determine whether relationships can be derived to long-term NERMN sites. Monitoring may need to continue beyond one year depending on the strength of relationships and the applicability of catchment models. Support: Suren (2014)

Gap theme	Gap	Recommendation
Data for models	Cumulative impact on receiving environments.	Consider the desired values in receiving environments (i.e. lakes), establish assimilative capacity of receiving environment for the chosen variable(s), and then work upstream into the catchment to ensure limits in receiving environment can be met.
Obtain new data	Contribution of groundwater (quality and quantity) to waterways.	Investigate the contribution of groundwater into the waterways within the WMA and the relative nutrient load contributed from the groundwater springs. Support: Boubee et al. (2009)
Spatial frameworks	Definition of spatial scale for limit setting.	Decision be made on the scale used for water management. For example, with 4402 km of waterways within the Rangitāiki WMA, are the same water quality limits going to be set for every waterway within the WMA (i.e. at a WMA level)? Or are limits going to be set at sub-catchment level?
Data for models	Model of water quality within the Rangitāiki WMA.	Investigate opportunities for model development (or modifying existing models) to support decision making and estimation of cumulative impact on waterways.
Obtain new data	Impact of drainage canals.	Investigate the impact the drainage network is having on downstream water quality. NOTE: The drainage network may come under Appendix 3 of the NPS. If so, this recommendation may not be required.
Obtain new data	Connection with wetlands and wetland extent.	Re-survey wetland extent, determine connection with waterways, and incorporate WQ monitoring in wetland monitoring programme where there is a hydrologic connection. Support: Hamill (2012).

Part 7: Lakes

7.1 Introduction

Whilst the Rangitāiki River flows north from the Kaimanawa Ranges and discharges to the coast near Thornton, two hydroelectric power schemes occur in the river, resulting in two dams: the Aniwhenua and Matahina dams. Lake Aniwaniwa occurs behind the Aniwhenua Dam, and is relatively shallow with an area of 2.1 km^2. Lake Matahina occurs behind the Matahina Dam, and is much deeper than Lake Aniwaniwa, with an area of 2.5 km^2 (Suren, 2014). A third hydroelectric power scheme exists in the upper catchment diverting water from the Rangitāiki and Wheao rivers, and Flaxy Creek, and discharging water back into the Wheao River. The upper part of the Wheao has been dammed in this scheme, but no lake has been formed behind this dam as all water is diverted into the artificial Flaxy Lake, before flowing through the hydro-electric station and back into the Wheao River.

The construction of dams on waterways and their resultant lakes changes the natural longitudinal connectivity of the waterway. River flow downstream of the dam becomes regulated and water quality (particularly suspended solids and nutrients) below the dam is often different to water flowing into the dam. The ability of fish to migrate between the ocean and headwaters can be interrupted unless provision for fish migration is made. Subsequently, monitoring lake health can provide an important link in understanding observed river health (e.g. water quality) above and below the lakes.

As the Rangitāiki River flows into both Lakes Aniwaniwa and Matahina, they are both considered receiving environments. These receiving environments often act like sinks, whereby contaminants delivered into the lakes by the river can accumulate over time. As water is released from the lakes back into the Rangitaiki River, the quality of the water released from the lakes has an impact on the river downstream.

7.2 Lake water quality

As these two lakes are artificially created for hydroelectric power generation they are not monitored as part of BOPRC's NERMN lake module, however both sites are monitored as part of the NERMN rivers module. Lake Aniwaniwa is monitored at the lake outlet, where the lake discharges back into the Rangitāiki River. Given the size and dynamics of the lake (shallow, run-of-river lake), this sampling location is deemed appropriate to assess overall lake water quality. In contrast, Lake Matahina is currently sampled at the edge of the lake. Given the nature of this lake (deeper and more likely to stratify over warmer months), the single 'edge' sample is not deemed appropriate to represent lake water quality. It is recommended that the Matahina sampling site be removed from the rivers module and the lake be sampled as part of the lakes module (monthly sampling of the water column at the deepest part of the lake).

The Rangitāiki River flows into both lakes, and as such, river and lake water quality are invariably linked. Suren (2014) conducted sampling of the lakes in 2013-2014 as part of the ecological assessment of the Rangitāiki River. This sampling occurred for five months from December 2013 until April 2014 and consisted of monthly water quality samples for total nitrogen, phosphorus, chlorophyll and secchi depth. This information was used to calculate the Trophic Level Index (TLI) for each lake. The TLI includes four key parameters, chlorophyll-a, water clarity, total nitrogen and total phosphorus. The TLI is a measure of the overall state of the lake and provides an indication of nutrient enrichment and the life-supporting capacity of the lake (Burns et al., 2000).

Results from Suren (2014) indicated that both lakes were nutrient enriched. Lake Aniwaniwa had an average TLI of 4.41 during the sampling period, classifying the late as eutrophic. Lake Matahina had an average TLI of 5.61, classifying this lake as supertrophic. Suren (2014) also found a reduction in total nitrogen concentration between Lake Aniwaniwa and Lake Matahina. Generally, water quality in rivers declines with distance downstream (Harding et al. 1999), thus the Rangitāiki River between Lakes Aniwaniwa and Matahina appeared contrary to this general trend. The most likely explanation for this reduction in total nitrogen is the uptake of nitrogen by prolific macrophyte growth observed in Lake Aniwaniwa.

Given the hydrologic connection between the Rangitāiki River, and Lakes Aniwaniwa and Matahina, and the role of macrophyte (aquatic weed) growth in reducing nutrient concentration in the Rangitāiki River, Suren (2014) recommended a continuation of monthly monitoring in both these lakes. This monthly monitoring recommendation aligns with national recommendations for lake monitoring (Davies-Colley et al. 2012).

As part of MfE’s national review of freshwater monitoring protocols and reporting (Davies-Colley et al. 2012), the key lake water quality recommendations from the report were:

- Sampling should ideally be monthly to enable trend analysis over time. Bimonthly (or indeed less frequent) sampling is not ideal for tracking changes in lakes, and the authors recommend that this option should only be considered where lakes may not be sampled at all.
- Sampling should take place from a boat to enable secchi depth and depth profiles to be completed.
- Sampling should occur in the deepest part of the lake.
- Constant sampling depths are preferred irrespective of thermal stratification. The authors note that the depth of the ‘surface’ sample may vary by lake, but should not vary over time. Surface samples should be sufficiently below the surface to avoid surface floating particles.
- If depth-integrated samples have historically been collected, this regime should continue to preserve consistency of the dataset.
- Temperature and dissolved oxygen depth profiles should be conducted on each sampling occasion.
- Secchi depth should always be recorded on each sampling occasion.

- Lake levels should be recorded on each sampling occasion.
- Lake TLI should be calculated for each sampling event prior to averaging to annual TLI.

Monthly lake water quality monitoring would enable the lakes to be assessed against the compulsory national values outlined in the NOF.

7.3 Lake macrophytes

As part of the consent to operate the Aniwhenua Dam, surveys of aquatic macrophytes (plants that grow mainly in the shallow areas around lakes) are required. These surveys are now conducted at five yearly intervals and the results are reported to BOPRC. The most recent survey conducted as part of the consent was in 2012 (Sharp and Tully, 2012). In 2014, NIWA conducted a single survey of Lakes Aniwaniwa and Matahina as part of routine Lake Submerged Plant Indicators (LakeSPI, de Winton et al. 2012) surveys conducted in the Rotorua Lakes. This survey was part of the ecological assessment conducted by Suren (2014). LakeSPI assesses and scores the native and invasive character of the observed vegetation, and synthesises these components to provide an overall measure of lake ecological condition. Results from the 2014 surveys are reported in Suren (2014) and a general summary is provided below.

In general, 50% of the species recorded in the two lakes were native species. Lake Aniwaniwa had a low LakeSPI index score of 12% with native condition scoring low at 8% and invasive condition scoring high at 95%. This contrasted with earlier surveys of the lake in 1983 in which the index was moderate at 24%, with native condition and invasive condition of 15% and 78% respectively. This decline in index score reflects increased macrophyte cover within the lake (Suren, 2014). Lake Matahina also had a low LakeSPI index score of 10%, with native condition and invasive condition scores of 3% and 96% respectively.

7.4 Gaps and recommendations

As a result of the surveys conducted in 2014, Suren made two recommendations for macrophyte management:

1. Develop an action plan to manage excessive introduced macrophyte growth where this impacted on recreational and aesthetic values; and
2. Investigate options and cost efficiencies for macrophyte control using different methods (e.g. herbicides or harvesting). The recommendations provided in Suren (2014) are still valid, and as such have been included below for completeness (Table 22).

Table 22 Identified gaps for lake water quality sampling and recommendations to fill gaps (from Suren, 2014).

Gap theme	Gap	Recommendation
Obtain new data	Lake water quality monitoring in Matahina.	Conduct monthly water quality monitoring in Lake Matahina consistent with recommended protocols. Support: Suren (2014), Davies-Colley et al. (2012)
Obtain new data	Management of lake macrophytes.	Develop an action plan for Lake Aniwaniwa where excessive growth of introduced macrophytes is severely impacting on aesthetic and recreational values. AND Undertake a cost-benefit-analysis of macrophyte control options (i.e. herbicide vs harvesting).

Part 8: Periphyton

8.1 Introduction

Periphyton is the term used to describe the slime that grows attached to rocks, stumps, and other stable substrates in rivers and streams. It is composed mostly of algae, although it can also contain quantities of fungi and bacteria. It is a natural component of rivers, and provides an important food source for invertebrates. It is also an important indicator in changes of water quality as any increases in stream nutrient levels may result in excessive growths of periphyton (called a bloom). Periphyton blooms have detrimental impacts on not only the ecological value of rivers, but also their recreational, aesthetic and cultural values.

Periphyton biomass can influence many in-stream values, such as recreation, aesthetics, and ecology. In recognition of this, MfE has produced interim guideline values for periphyton biomass for the maintenance of aesthetics, benthic biodiversity, and trout habitat and angling (Biggs, 2000). These guidelines use a measure of either cover estimates of diatoms/cyanobacteria or filamentous algae, or measures of chlorophyll-a (the photosynthetic pigments that is found in all algae). For example, maintenance of aesthetics and recreation would be achieved in rivers having less than 60% cover of a thin (<0.3 cm thick) diatom films, or less than 30% cover of filamentous algae (less than 2 cm long). Benthic biodiversity would also be maintained if a maximum of chlorophyll-a concentration of <50 mg m^{-2} is maintained (Biggs, 2000).

More recently, (Matheson et al. 2013) highlighted a number of limitations of the Biggs (2000) guidelines. One was that the MFE guidelines provided separate thresholds for mat forming algae (such as the diatoms and cyanobacteria) and filamentous algae. However, it is possible for combined cover by both types of periphyton to be high, while cover by each type is below the MfE threshold. For example, 30% cover of diatom/cyanobacterial mats combined with 25% cover of filamentous algae (each of which meets the respective MFE guideline) is likely to constitute an unacceptable condition which would negatively impact in stream values. To solve this anomaly, Matheson et al. (2013) recommended the use of a periphyton weighted composite cover (PeriWCC) such that:

$$PeriWCC = \%\ filamentous\ cover + (\%\ mat\ cover/2)$$

Matheson et al. (2013) also suggested four bands for PeriWCC such that <20% = “excellent”; 20 – 39% = “good"; 40 – 55% = “fair"; >55% = “poor”. They showed that invertebrate metrics such as the MCI, QMCI and percentage of EPT responded in a relatively consistent manner to increases in PeriWCC, and suggested that these four bands could form the basis of provisional general periphyton cover thresholds to protect benthic biodiversity.

Because of its importance in affecting many in stream values, periphyton biomass (expressed as measurements of chlorophyll-a) is a compulsory attribute under the NOF. Although monitoring periphyton biomass using chlorophyll-a is relatively expensive, Snelder et al. (2013) highlight that this is a single and relevant variable representing periphyton abundance which has been used extensively in New Zealand and overseas. Statistical models relating periphyton biomass to other factors such as water chemistry and flow regimes are generally stronger for Chlorophyll-a than for other measures such as percent cover. Finally, Snelder et al. (2013) emphasise that chlorophyll-a is a standard metric for measuring periphyton abundance internationally, so that any advances in our understanding of factors controlling periphyton growth can be more easily applied if this metric is used in New Zealand.

The NOF sets four bands (A to D) for periphyton biomass, with the D band representing conditions that fail to meet the national "bottom line". The NOF chlorophyll bands also include an exceedance frequency, recognising that even streams flowing through unmodified catchments can experience short lived (weeks to months in duration) algal blooms. However, stream ecosystems are highly resilient to short term algal blooms, and ecological health will generally not decrease if these blooms do not persist for more than a short period of time (Suren et al. 2003a).

8.2 Periphyton monitoring in the Bay of Plenty

BOPRC currently does not monitor periphyton cover, either through the annual invertebrate monitoring programme, or the monthly water quality monitoring programme. This lack of monitoring constitutes a major gap in ecological monitoring and highlights that there is no present ability for BOPRC to comment on either the current state of periphyton biomass in the region (or Rangitāiki WMA), or to consider the need for nutrient limits to keep periphyton biomass at acceptable levels (Table 23). This this is a major knowledge gap when considering the degree to which periphyton biomass can affect a wide range of in-stream values such as ecology, recreation, athletics and cultural. This knowledge gap was also highlighted in the report by Suren (2014) that summarised the current ecological conditions of waterways throughout the Rangitāiki. There is limited monitoring of blue green algae cover in some rivers throughout the region. This is restricted to weekly or fortnightly monitoring of cover during the summer months only.

The amount of periphyton in a stream is generally regarded as a function of both nutrient status and stream flow regime. If BOPRC is to set freshwater objectives that include periphyton biomass in streams, and set limits to resource use accordingly, then we need to understand the interactions between nutrients and flow, and periphyton biomass. Such interactions will also be controlled by other factors such as stream shade and substrate stability. Monitoring periphyton in the region also needs consideration of where such monitoring sites should be.

A document is currently being prepared by BOPRC to outline issues such as where samples should be collected, what other parameters should be collected, and the methods behind these.

8.3 Gaps and recommendations

Table 23 Identified gaps for periphyton sampling and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Obtain new data	Knowledge is required of periphyton biomass (both spatial and temporal variability) of selected sites throughout the Rangitāiki WMA.	Periphyton biomass be monitored at selected sites throughout the Rangitāiki WMA. This supports recommendation (ii) in Suren (2015)
Obtain new data	Lack of detailed information on the extent of problem *Phormidium* blooms.	As part of algal monitoring, monitor the cover of dominant algal groups, including *Phormidium*. This will provide information as to the spatial and temporal extent of any algal blooms
Spatial frameworks	Under the NPS-FW, councils are expected to create their own Freshwater Management Units. These units need to represent streams which are similar to each other, so that appropriate bands for the compulsory national attributes can be accurately determined.	BOPRC needs to consider which spatial framework is used to create fresh freshwater management units. These units could be based on either the REC or FWENZ classifications, or an alternative. To assist with decision-making, it may be cost-effective to get input from external experts on this matter.
Data for models	Linkages between periphyton, nutrients and flow.	Where possible, any periphyton monitoring should be done at sites where monthly water quality data is collected, and within continuously gauged catchments, or close to such catchments. This will allow BOPRC to: i) test current models of algal/nutrient interactions ii) Develop new models of interactions between algae and nutrients

Part 9: Cyanobacteria

9.1 Introduction

Cyanobacteria are a group of organisms that live naturally in fresh water worldwide. Because they have chlorophyll, they behave like plants and are capable of photosynthesis. Cyanobacteria are often referred to as 'blue-green algae' even though they are not actually algae. Cyanobacteria can be benthic (live attached to the bottom of a stream) or planktonic (not attached to anything and live floating in the water column). Under certain environmental conditions, such as high levels of light and nutrients and warm water temperatures, cyanobacteria can multiply and congregate to form blooms. For planktonic cyanobacteria, blooms usually present as pea-coloured, soupy looking water or scum on the water surface which may also smell "earthy" or "musty".

Benthic cyanobacteria form part of the periphyton and blooms often show up as light brown or black mats that cover large cobbles and boulders on the river bed. Some species of cyanobacteria produce toxins which may be harmful to humans and other animals that come into contact with the toxins. In lakes, these toxins have been responsible for fish deaths, as fish swim through and accidentally ingest the small planktonic algae. In rivers, dog deaths have occurred when dogs are attracted to the distinctive smell of cyanobacterial mats that have become dislodged from the riverbed, and which have been washed up on the edge of the river. Fortunately, river cyanobacteria are often quickly washed away from rivers during periods of high flow, and so often disappear in autumn with the onset of seasonal rain.

9.2 Cyanobacterial monitoring in the Bay of Plenty

Because of the potential health risks of cyanobacteria blooms, BOPRC monitors planktonic cyanobacteria in the Rotorua Lakes and the Kaituna River (which is fed from both Lake Rotoiti and, following the completion of the Ōhau Channel, Lake Rotorua). The lake cyanobacteria monitoring programme was initiated in the Rotorua Lakes in 1997 in response to blooms that exceeded safe levels for drinking and contact recreation (Scholes, 2009). The core monitoring programme consists of collecting weekly samples over summer from 15 sites in four lakes (Ōkaro, Rotoehu, Rotoiti, Rotorua), and from three sites in the Kaituna River. Other lakes are surveyed on a case by case basis based on complaints from members of the public.

All cyanobacterial samples are analysed for cell count and biovolume – a combination of the number of cells counted and the overall size of individual cells. All biovolume results are assessed in line with the Interim New Zealand Guidelines for cyanobacteria (MfE/MoH, 2009) to determine the level of health risk. There are three guideline levels:

- Green = biovolume below threshold levels, no health warnings in place.
- Amber = biovolume between 0.5–9.99 mm3/L; increase monitoring to weekly.
- Red = biovolume >10 mm3/L; initiate public health warnings and potentially consider implementing intervention activities such as alum dosing to help lock up excess nutrients.

A summary of all results is sent weekly to BOPRC lakes operations staff, Rotorua Lakes Council, and Toi Te Ora Public Health. During red alert levels, monitoring is sometimes increased to better determine how long blooms last, and also to monitor the effectiveness of any interventions that may be employed.

There are only three lakes within the Rangitāiki WMA: the two hydro lakes (Lake Matahina, located in the lower reaches of the Rangitāiki River just above the Rangitāiki Plains, and Lake Aniwaniwa, located in the downstream area of the Galatea Plains), and Lake Pouarua, located at the head of the Rangitāiki Catchment. Although both lakes Matahina and Aniwaniwa have high recreational values, no routine cyanobacterial monitoring has been undertaken there. While this may appear to be a data gap, as far as we are aware, there have been no public complaints about cyanobacterial blooms in either of these lakes. There was, however, a bloom of *Hydrodictyon reticulatum* that occurred in Lake Aniwaniwa from 1989 until 1994 which had localised impacts on the biota of the lake. These algae also formed extensive blooms on other lakes such as Lake Rotorua, and bloom resulted in a considerable amount of public concern, and subsequent scientific work being done to understand the causes and impacts (e.g., Wells and Clayton 2001).

The absence of public complaints over cyanobacterial blooms in either Lakes Aniwaniwa or Matahina imply that BOPRC does not need a monitoring programme in these two lakes. Lake Pouarua is located in the Lochinvar Station on private property, and as such would have minimal recreational values. Again, we can see no reason why a cyanobacterial monitoring programme needs to be undertaken for this lake as well.

BOPRC also monitors benthic cyanobacteria (*Phormidium*) in rivers known to experience blooms. This programme was initiated in 2007 in response to a dog death near Edgecumbe, in the lower Rangitāiki River, where a dog ingested some detached *Phormidium* that had become trapped in some floating aquatic plants. The origin of this detached clump of cyanobacteria in the river is unknown, but most likely would have come from some upstream areas of stable rip-rap that occur along the river. The monitoring programme runs over the summer-autumn period (when blooms are most likely), especially when river flow has been stable, and when *Phormidium* can grow without being washed away during flood events. Monitoring includes estimating the percentage cover of *Phormidium* at five points along four transects at each site, with the mean percentage cover calculated from all 20 observations (Scholes, 2014).

Typical rivers where *Phormidium* blooms can occur are wide, cobble-bed rivers, with shallow, fast flowing water. Such rivers include areas of the Rangitāiki, Whakatane, Otara and Waimana Rivers in the central Bay of Plenty region, and the Uretara, and Te Rereatukahia Rivers in the Western Bay of Plenty. *Phormidium* favours these conditions as cobbles provide a stable place for them to attach, and fast flowing water means that they can more efficiently take up nutrient such as nitrogen from the water column. However, *Phormidium* mats have also been observed growing in pumice-bed streams during periods of extended low-flow as this highly mobile material is not easily moved under such conditions (Scholes, 2014).

Within the Rangitāiki WMA, BOPRC has monitored *Phormidium* cover in six sites since 2009. Three of these sites have been in the lower Rangitāiki River below Te Teko, and three have been in the mid reaches in the Galatea Plains. The lower three reaches never recorded *Phormidium* cover exceeding in green alert threshold (i.e., stream bed cover less than 20%), while two of the sites in the Galatea plains (Galloways and Murupara bridge) commonly recorded *Phormidium* cover between 20 and 50% of the streambed (i.e. at Amber alert threshold). Cover exceeded 50% at the Murupara bridge site on one occasion in February 2010, but had decreased one month later back to green alert levels.

Suren (2014) also observed that *Phormidium* mats covered relatively large areas of the stream bed in some shallow, fast-flowing riffles in the Rangitāiki river upstream of the Matahina and Aniwhenua dams. The relatively large cover of *Phormidium* in this river was thought to reflect a combination of warm temperatures and stable low flows. Moreover, Suren (2014) suggested that the extent of *Phormidium* blooms in the Rangitāiki may increase with increasing nitrogen concentration in the water which has been observed in the Rangitāiki below Murupara.

9.3 Gaps and recommendations

Although lake cyanobacteria are a compulsory attribute under the NOF, it is suggested not to implement a lake cyanobacterial monitoring programme within the Rangitāiki WMA. This reflects the absence of any public concerns over potential health concerns in either of the two hydro lakes, and the fact that Lake Pouarua is located on private property within Lochinvar Station, where recreational values are likely to be low.

The NOF also stipulates that planktonic cyanobacteria be monitored in lake-fed rivers. The only lake fed river in the Rangitāiki Catchment is a stream draining Lake Rerewhakaaitu. Total phosphorus concentrations are in either the NOF A or B bands, while total nitrogen concentration is in the NOF B band. Average annual maximum chlorophyll in this lake has been consistently in the NOF A band since 2009/2010. These results suggest that cyanobacterial blooms in this lake are highly unlikely. This stream also flows predominantly through the pine plantation in the Kaiangaroa Forest, and so is unlikely to have a large amount of recreational activity. As such, it is not recommended that planktonic cyanobacteria are monitored in this lake-fed river.

Although benthic *Phormidium* is not included as a NOF attribute, it is recommended that the current relatively ad hoc monitoring programme for *Phormidium* is more formalised. It is suggested that the planned periphyton monitoring programme also includes a component of monitoring *Phormidium* cover at the selected sites (Table 24). This would be done as part of visual observation monitoring for periphyton cover of other algal groups such as diatoms, and filamentous green algae. Although sites for the periphyton monitoring have yet to be chosen, it is planned that sites where the current *Phormidium* monitoring is underway could be included as part of the overall periphyton monitoring programme.

Table 24 Identified gaps for cyanobacterial monitoring and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Obtain new data	Benthic cyanobacterial cover is not a compulsory national attribute.	Given the potential danger of *Phormidium* proliferations to river users, combine *Phormidium* monitoring with routine periphyton monitoring.

Part 10: Stream invertebrates

10.1 Introduction

Traditional physical and chemical measures of water quality are useful to help determine sources of water contamination, but they only indirectly measure the health of the aquatic ecosystem because they don't look directly at biological responses to pollution. The most direct way to understand the health of a river ecosystem is to monitor the animals and plants living in the river. Unlike water chemistry, which may be highly variable from day to day depending on the timing of discharges, and river flow patterns, stream invertebrates integrate all chemical, physical, and biological influences in their habitat over their lifecycle, which in some cases can be many years. As a result, the numbers and types of invertebrates in a water body reflect the quality of their surroundings. Stream invertebrates are thus used by all regional councils throughout New Zealand to help them assess the ecological condition of rivers, and to assist in their statutory responsibilities for environmental monitoring.

A central part of using freshwater invertebrates to monitor stream health is the creation of biotic indices. These numbers are used to reduce the inherent complexity of ecological data (i.e., multiple species found at multiple sites), allowing resource managers to tell at a glance how healthy a particular waterway is. The most commonly used biotic index in New Zealand is the Macroinvertebrate Community Index (MCI), and it's quantitative variant (QMCI). Use of these two metrics is further simplified by the creation of four water quality classes based on the value of the MCI/QMCI (Stark and Maxted, 2007). Thus, streams with an MCI greater than 120 are regarded as being in "excellent" condition, while streams with an MCI less than 60 are regarded as being in "poor" condition.

10.2 Invertebrate monitoring in the Bay of Plenty

A number of studies have surveyed invertebrate communities at sites throughout the Rangitāiki WMA as part of consent investigations, impact assessments, state of environment monitoring or targeted research programmes (Table 25). Prior to 2013, samples had been collected from only 49 sites throughout the catchment. The most extensive sampling programme had been conducted as part of the Council's NERMN programme, where eight sites in the Rangitāiki had been sampled more or less annually every summer.

A number of other studies have surveyed invertebrate communities at sites throughout the catchment as part of the resource consent process or compliance investigations. The most extensive sampling programmes were done as part of the resource consent investigations for the Rangitāiki-Wheao hydroelectric scheme. Here, Bioresearchers Limited (1976) first reported the ecological values of three sites in the upper Rangitāiki River above the confluence with the Wheao River, three sites in the Whaeo River, and two sites in Flaxy Creek. This initial report was followed by six further reports (Bioresearchers Limited 1985a; Bioresearchers Limited 1986a and 1986b; Bioresearchers Limited 1988; Bioresearchers Limited 1989; Bioresearchers Limited 1990; Bioresearchers Limited 1991) examining changes to the fish and invertebrate communities following completion of the Rangitāiki-Wheao hydroelectric scheme. These reports sampled a subset of sites (four only) originally sampled by Bioresearchers in 1976.

Bioresearchers Limited (1979 and 1985a) also examined the effects of dairy effluent from the Rangitāiki Plains Dairy Company. They monitored water quality and examined invertebrate communities at two sites 500 m above and below the effluent discharge. At each site, they examined water quality and invertebrate communities on the east and west banks of the river, and concluded that there was little evidence of an adverse effect on the invertebrate communities from the dairy discharge.

As part of a resource consent renewal for the Matahina Dam, Kingett Mitchell (2001) undertook an ecological survey of the Lower Rangitāiki River. Here, they examined fish, invertebrate, macrophytes and periphyton communities at three sites in the Rangitāiki River at increasing distances below the Matahina Dam. The upper site was located approximately 1.5 km down from the dam, while the middle site was approximately 5.5 km downstream. The lower site was 3.5 km downstream of Edgcumbe. Invertebrate samples were collected from macrophytes only, so other habitats in the river such as shallow gravel bars and deep, unvegetated parts of the river were not sampled. The same relatively shallow macrophyte dominated sites were also resurveyed by Kingett Mitchell in 2003 and 2004. The data from the Kingett Mitchell work forms the basis of a recent consent application by TrustPower.

Finally, as part of the National Water Quality Monitoring (NWQM) Programme, NIWA has collected samples from three locations in the Rangitāiki Catchment, at the Whirinaki River, Murupara, and Te Teko. This annual sampling has been running since 1989, and represents the longest sampling programme conducted in the Rangitāiki.

Table 25 Number of sites that had been sampled which were resurveyed as part of the contemporary survey (Suren 2014). Also shown is the number of years separating the two data sources.

Organisation	Study	Reason	Years between surveys	Number of sites
Bioresearchers	Upper Rangitāiki and Wheao Hydroelectric Ecological investigations.	Consent investigations.	1975 1983-1991	13
Bioresearchers	Effects of the discharge of dairy effluent at Edgecumbe.	Impact assessment.	1978 1984	8
Kingett-Mitchell	Re-consenting process for the Matahina Dam.	Consent investigations.	2001-2004	3
BOPRC	Natural Environment Resources Monitoring Network (NERMN) Programme.	State of Environment monitoring.	Since 1992 (two sites) or 2001 (two sites)	14
BOPRC	Ecological studies of Rangitāiki Catchment.	Targeted research for Rangitāiki River Forum.	2014	117
NIWA	National Water Quality Monitoring Network.	State of Environment monitoring.	Since 1989	3
NIWA	Ecological studies of upper Rangitāiki Catchment (Lake Aniwaniwa and upstream).	Targeted research for Ngati Manawa.	2008	8

Prior to the extensive ecological survey conducted in 2013 and 2014, Suren (2014), examined the historic invertebrate sampling sites according to their REC classification and stream order size. This analysis showed that most samples (39%) were collected from the main stem of the Rangitāiki Rivers, while another 35% of samples were from large rivers (orders five and six). Only 23% of samples (i.e. seven) had been collected from small-medium sized rivers (order three and four), and only one sample (the Mangapapa) has been collected from a small stream. Large discrepancies thus existed between where sampling has occurred and the numerical abundance of smaller waterways in the catchment. A majority of samples (65%) had also been collected from streams dominated by exotic plantation forest, over-representing this land use type. Furthermore, only 6% of streams were collected from streams draining native forest, considerably less than the 25% of stream length in the catchment that drains native forest.

This analysis showed that large gaps existed in our knowledge of the invertebrate communities (and therefore overall ecological health) of waterways throughout the Rangitāiki Catchment. Little or no sampling had been done on the main stem of the Rangitāiki River above Lake Matahina, and what had been sampled above there was now over 20 years old. Furthermore, very little ecological information existed for the many smaller rivers and streams draining into the Rangitāiki River from both largely unmodified native bush forests on the eastern part of the catchment, and the more modified waterways draining pine plantation and forestry on the western side of the catchment. These knowledge gaps were the main impetus behind the large-scale ecological survey conducted in 2013-2014, where 117 sites were sampled throughout the catchment.

Suren (2014) found that most of the streams surveyed supported invertebrate communities typical of streams in “good” or "excellent" health based on the MCI. Invertebrate composition differed greatly between streams, reflecting differences in river size, location, dominant land cover, and water quality (particularly the nutrient nitrogen). Highest stream health was in streams draining native bush and exotic forest. Stream health was lowest in streams draining pasture and was especially low in the main stem of the Rangitāiki River on the plains.

Many of the streams sampled as part of the ecological survey were chosen to re-sample sites which had been sampled previously. In this way, any changes to invertebrate community composition over time could be identified. Suren (2014) found that invertebrate communities (and by definition, ecological health) had not changed much over a 30-year period, even in streams draining pasture catchments. Lack of changes to stream health in highly modified pasture streams suggests that stream health changed before the earliest surveys (30 years ago) and that communities currently found have shifted to a new stable state.

Given the fact that the large-scale ecological survey was done as a result of the identification of knowledge gaps, it is thought that no further sampling of invertebrate communities is required in the Rangitāiki WMA over and above that which is currently being conducted as part of the Council's NERMN programme. It must be noted that, as part of a review of the NERMN stream invertebrate monitoring programme, extra sites within the Rangitāiki WMA draining streams in catchments dominated by plantation forestry have been incorporated into the annual invertebrate monitoring programme, to help fill gaps that were apparent in this programme (Table 26).

In his report, Suren (2014) emphasised the importance of ecologically relevant spatial classifications. He highlighted the importance of a special classification framework that would classify waterways into groups that shared specific characteristics. This is because biological communities and ecological processes are likely to differ between stream types – even within a single catchment such as the Rangitāiki. Classification also allows comparison of rivers draining different land uses to be made, e.g. pasture with native bush or plantation forest, but a series of specific “rules” are needed to assign a stream to a specific land use class.

Suren tested a number of different spatial frameworks to see which ones explained most of the observed variability to invertebrate communities. Eight such spatial frameworks were tested, including one developed based on a classification of streams according to measured habitat features, one based on the physical location of waterways in the catchment, and one based on stream size class. Four other classifications were based on the individual REC groupings of climate, source of flow, geology and land cover. The last spatial classification was based on the water quality classification as used in the Regional Water and Land Plan.

The classification based on habitat features explained the most variability to the invertebrate communities, followed by the classification based on location in the catchment, land cover, and stream size. Classifications based on the individual REC groupings of climate, source of flow and geology within the Rangitāiki explained less of the variation. This presumably reflected the fact that these environmental factors operated at large spatial scales throughout the Rangitāiki, and so would have masked any effects of environmental factors operating at smaller spatial scales. For example, 86% of waterways in the Rangitāiki were classified in the “Cool-wet” climate class, yet many of these waterways would have drained catchments dominated by different land uses, and would include a wider range of river size.

10.3 Gaps and recommendations

This result highlights the need to ensure that any special classification that is chosen to represent a freshwater management unit within the Rangitāiki WMA has sufficient resolution to identify and separate out streams that share a suite of common characteristics between each other (Table 26). In this way, the chosen spatial classification would successfully explain natural variability in parameters such as invertebrate communities.

Table 26 Identified gaps for ecological sampling and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Spatial frameworks	Freshwater Management Units need to be made at relevant spatial scales to represent streams which are similar to each other. In this way, BOPRC can accurately convey the current state of water ways in each WMA to community groups with greater clarity.	Decide on what spatial framework will be used to create freshwater management units.
Obtain new data	Increased knowledge is required of invertebrate communities in under-represented sites such as streams draining plantation forests.	Increase the number of monitoring sites in plantation forests as part of the NERMN programme. This has already been implemented.

Part 11: Fish communities

11.1 Introduction

One of the most important ecological values of rivers and streams for most people would undoubtedly be fish communities. Freshwater fish historically sustained iwi who developed a very close relationship with the natural life cycle of many of New Zealand's native freshwater species to ensure they could harvest this bountiful supply (McDowall 2015). With the arrival of European settlers, introduced fish such as salmon and trout were liberated throughout the country, and these have now formed the basis of a hugely important recreational resource throughout the country (McDowall 1990).

Despite their importance, many fish (both native and introduced) are being adversely affected by human activities throughout New Zealand. In particular activities associated with agricultural development such as removal of riparian vegetation, channel straightening and ongoing drain maintenance, water abstraction and inputs of nutrients and sediments are having demonstrable effects on fish communities throughout the country. Furthermore, large hydroelectric dams have affected the ability of native fish to successfully complete their life cycle as they have blocked free access to and from the sea. Finally, many native New Zealand fish have been displaced by the larger and more aggressive introduced trout and salmon.

11.2 Fish monitoring in the Bay of Plenty

As with many councils BOPRC currently does not monitor fish communities routinely. Any fish work conducted by BOPRC is usually for focused studies conducted as part of Council investigations. Other organisations such as NIWA, Department of Conservation (DoC), and Fish and Game have also conducted numerous fish surveys throughout the region. Finally, a number of consultancies have also surveyed fish communities as part of either consent applications or for compliance monitoring. Most fish data collected from the region has been uploaded into the New Zealand Freshwater Fish Database (FFDB), maintained by NIWA. The FFDB contains over 30,000 records of freshwater fish observations throughout the country, and represents a nationally significant database.

Data from the FFDB have also been used to produce predictive models of fish distribution throughout New Zealand. These predictive models show the probability of occurrence of different fish species in the absence of human activities. They could thus be used to assess the degree to which fish communities have been affected by human activities throughout the catchment by comparing observed and predicted fish distributions.

A number of different fish surveys have been undertaken in the Rangitāiki WMA. These have examined the fish fauna of Lakes Matahina and Aniwaniwa (Smith et al. 2007, 2008; Kearney et al. 2013a), the main stem of the Rangitāiki River below Lake Matahina (Kearney et al. 2013b), selected tributaries in the Whirinaki Catchment (Young 2000, Smith et al. 2007), and the upper reaches of the Rangitāiki and Wheao rivers (Bioresearchers 1976-1991).

Early fisheries surveys in the catchment were done by Bioresearchers (1976–1991), who examined sites in the upper Rangitāiki River as part of consent or compliance investigations for the Rangitāiki-Wheao hydroelectric scheme. These reports concentrated mostly on trout, but did record presence of other fish when encountered.

Smith et al. (2009) also surveyed a number of tributary streams in the upper Rangitāiki River Catchment upstream and downstream of Lake Aniwaniwa. Most of the streams were electro-fished close to their confluence with the main stem of the Rangitāiki River. Catchment land use in these streams was dominated by either exotic forestry or farming, although many sites had riparian margins of scrub or native bush. The only fish encountered were trout (rainbow and brown) and eels (longfin and shortfin). Young (2000) also surveyed 18 tributary streams in the Whirinaki River, and encountered a similar fauna.

The National Institute of Water and Atmospheric Research (NIWA) coordinated a multi-disciplinary study of the Rangitāiki River above Lake Aniwaniwa, investigating parameters such as soils, land use, rainfall, surface and groundwater hydrology, water quality and ecology, and produced a large (352 pages) report in 2009. In this report, they comment that the diversity, distribution and quality of native fish such as tuna (eel) and kokopu have declined in the upper Rangitāiki, reflecting fish passage issues, over exploitation, loss of habitat, and competition from trout. They also do not know if isolated populations of native kokopu still remain, and if so, how to protect them and their habitat.

In total, only nine fish have been recorded in the Rangitāiki River above Lake Matahina. Of concern, is the finding that dwarf galaxias (*Galaxias divergens*) have been recorded only four times, twice in 1966, and again in 1992 and 1997. The only other records of galaxiids are of giant kokopu from Lake Matahina in 2007 and 2008: it is assumed that these fish also live in some of the tributary streams draining into this lake. Despite the lack of other confirmed galaxiid sightings, it is also thought that landlocked populations of koaro and banded kokopu could also be present above the dams, as these fish can form land locked populations elsewhere in New Zealand.

Many of the tributary streams were surveyed up to 13 years ago, and many of the smaller streams in the area have not yet been surveyed. In a review of ecological work conducted in the Rangitāiki WMA, Suren (2013) suggested that a new fish survey focus on re-surveying some of the sites examined by Bioresearches (1976–1991), Young (2000), Smith et al. (2008) and NIWA (2009), as well as surveying some new sites yet to be examined. A new survey was subsequently undertaken in 2014, where 82 sites were surveyed. Some of these sites were resurveying areas where previous surveys had been undertaken, while other sites were surveying areas for the first time.

Fish were found in 66 of these 82 sites. A total of eight fish species were encountered in the survey, and 1152 individual fish caught. Brown and rainbow trout were the most numerous species encountered, making up 55 and 15% of total abundance respectively. The next most commonly caught fish were longfin eels (12%), followed by dwarf galaxias (11%) and shortfin eels (4%). Longfin eels and rainbow trout were the most widespread species, and found in 44 and 42 sites respectively. Brown trout and shortfin eels were the next most widespread species, found in 19 and 12 sites respectively.

The large number of dwarf galaxias caught was surprising given the fact that these fish have only been previously reported from three sites in the catchment, and that these fish were thought to be in a state of population decline. Previous surveys of dwarf galaxias in the 1960s showed that they were found in the Horomanga River, the Kotuku Stream, and the Tukuhouhou Stream, with densities in the Tukuhouhou Stream being particularly high (100 individuals encountered). No dwarf galaxias were found in the same sites when resurveyed in 2014. Instead, only large numbers of rainbow trout were found. For example, 94 rainbow trout were found in an area of 60 m² in the Horomanga River site. These results reinforce the negative interaction between introduced trout and small native fish such as dwarf galaxias, and highlight the fact that when trout are able to colonise a stream, native fish such as galaxiids often disappear.

Two surveys were undertaken in the Kopuriki Stream in the 1990s, which showed relatively high densities of dwarf galaxias (30 individuals per 50 m²). Similarly high densities were recorded in the present survey from the same site, with 42 individuals being found from approximately 35 m². Good populations of dwarf galaxias were also found in the Ohutu Stream, and only one rainbow trout was caught here. The large numbers of dwarf galaxias in at least these two streams suggests that populations where encountered appear to be relatively healthy.

Of further interests was the finding of koaro in four streams. This represents the first records of this species for the Rangitāiki WMA. These streams include two sites on both the Te Weramata Stream and Okahu Stream. Some of these sites had been surveyed previously and yet koaro has never been recorded, so the presence of koaro in the catchment now may reflect the trap and transfer work being undertaken.

Many of the sites surveyed around the Whirinaki and its tributaries were previously surveyed by DoC in the early 2000s. This earlier survey found that numbers of longfin and shortfin eels in the Whirinaki Tributaries were low. Preliminary analysis suggests that the number of eels at the same sites resurveyed in 2014 is slightly higher, again suggesting that the trap and transfer work appears to be successful in relocating eels into sites where they were once uncommon or absent. Further analysis needs to be done to confirm this trend (Table 28).

Many of the fish studies (Smith et al. 2007, 2008; Kearney et al. 2013) also focused on assessing the population structure, size distribution and growth rates of both shortfin and longfin eels. For example, Smith et al. (2009) compared size distributions (length and weight) of both eel species in lakes Matahina and Aniwaniwa from 1988, 1996, 2007 and 2008, based on eel numbers caught in coarse mesh fyke nets deployed in each lake. They found that both the length and weight of both species had decreased over time between the studies, with a trend for smaller eels to be found.

Smith et al. (2008) also found that eel density was low in most tributaries. Many of these tributaries were generally fast flowing streams with gravel beds, which are better suited to trout and longfin eels. These habitats are not particularly suitable for shortfin eels: the most commonly encountered species in the upper catchment. However, Smith et al. (2008) also noted that a number of soft-bottomed streams did support good numbers of shortfin eels, and suggested that some of these streams could be better protected and enhanced to increase shortfin densities in the area. Finally, Smith et al. (2008) suggested that growth rates of both species may be slowing in the lakes, so they recommended that the population be monitored at three to five year intervals.

Kearney et al. (2013) assessed the distribution and abundance of eels in lakes Matahina and Aniwaniwa in 2012 and 2013. Unfortunately, Kearney et al. (2013) did not compare their results with results from the earlier studies (Table 27). Many of the sites they sampled had not been sampled by Smith et al. (2007, 2008), and different methods were used between the two studies (e.g. Smith et al. used 12 mm coarse nets, while Kearney et al. 2013 used 20 mm mesh nets). Such differences may confound successful comparisons of the more recent data with the older data. However, assuming that each of the studies caught a representative proportion of the eels within each lake, initial examination of the long-term data suggest a decline in weight of both species from Lake Aniwaniwa, and a potential decline in the weight of shortfin eels in Lake Matahina (Table 27). It would be a useful exercise to obtain all the raw data from the previous eel surveys (from both NIWA and the Awanuiārangi) to better examine changes in eel size in both locations, assuming that the two data sets are comparable (Table 28).

Table 27 Summary weights of shortfin and longfin eels collected at Lakes Matahina and Aniwaniwa from NIWA (2008) and Kearney et al. (2013). Note an apparent slight reduction in average weight of Shortfin eels in Lake Matahina, and of both species in Lake Aniwaniwa. These trends need to be confirmed by comparison of all the raw data from both surveys combined.

Location	**Year**	**Shortfin eel**			**Longfin eel**		
		Sample size	Average weight	Max weight	Sample size	Average weight	Max weight
Matahina	1988-1989	132	699	1,800	42	1,023	1,300
	1996	96	570	3,320	14	1,454	3,300
	2007	80	510	1,830	16	1,170	2,850
	2008	135	400	1,810	11	1,000	2,250
	2012	52	526	1,714	68	1,103	9,750
	2013	87	393		46	780	
Aniwaniwa	1996	105	656	1,470	5	1,500	10,000
	2007	53	510	1,470	4	460	600
	2008	252	350	180	10	510	1,550
	2012	202	413	1,109	23	410	1,477
	2013	94	362		23	207	

11.3 Gaps and recommendations

Table 28 Identified gaps for fish survey work, and recommendations to fill gaps.

Gap theme	Gap	Recommendation
Improvements to methods and reporting	Long-term trend analysis of fish population structure in the Rangitāiki. This information is important to help assess the impact of the trap and transfer programme.	Need to undertake further analysis of recent fish survey data to determine if trap and transfer protocols are having positive effects (e.g. are longfin eels more common throughout the catchment?).
Improvements to methods and reporting	Lack of long-term monitoring data on eels stocks in Lakes Aniwaniwa and Matahina.	Obtain all raw data from previous eel surveys (NIWA and Te Whare Wānanga o Awanuiārangi) to better examine changes in eel size in both locations.

Part 12: Wetlands

12.1 Introduction

The Resource Management Act (RMA) 1991 definition of a wetland is broad and includes permanently or intermittently wet areas, shallow water, and land water margins that support a natural ecosystem of plants and animals that are adapted to wet conditions (Peters 2012).

Characteristics which distinguish wetlands from other terrestrial and freshwater ecosystems include shallow standing water and/or waterlogged soils, anoxic conditions (the absence of oxygen) in the soil, and dominance of emergent aquatic plants (Sorrel & Gerbeaux 2004, Ausseil et al. 2008).

New Zealand has committed to wise use of wetlands as a party to the Ramsar Convention 1976, has identified protection and preservation of wetlands as a matter of national importance under the RMA 1991, and has included wetlands as one of four national priorities for protection of biodiversity on private land (MFE 2007).

The NPS-FW (2014) specifically identifies the need to protect the significant values of wetlands and attributes, for wetlands are currently being developed for inclusion in subsequent versions of the National Objectives Framework (NOF) (MFE 2013, Clarkson et al. 2015).

The three key threats impacting on the ecosystem health of wetlands are loss of wetland extent, excessive nutrient and sediment inputs, and hydrological alteration. These three factors act cumulatively to alter wetland processes, and result in altered wetland plant communities and reduced species diversity.

12.2 Wetland monitoring in the Bay of Plenty

BOPRC’s NERMN regional wetland monitoring programme has been designed to collect information on the condition of wetlands in the region. The methodology (refer Clarkson et al. 2014) involves collection of soil and foliage samples (physico-chemistry) and assessment of species composition (percent cover) within 5 x 5 m vegetation plots, as well as field based assessment of ‘Wetland Condition Index’.

A regionally representative set of wetlands has been selected for this monitoring programme based on rarity, current extent, distribution, ecological district, ecological significance ranking, and adjacent land uses (Fitzgerald et al. 2013). There have been 11 wetlands selected from the Rangitāiki WMA for inclusion in the programme, but have not yet been measured as the programme was only initiated in 2014/2015.

12.3 Current wetland state in the Rangitāiki WMA

In the absence of data from the NERMN regional wetland monitoring programme, the best and most comprehensive data sources available for assessing overall state of wetlands in the Rangitāiki WMA include:

- Waters of National Importance project (WONI).
- Freshwater Environments of New Zealand (FENZ).
- BOPRC ‘WetlandExtents’ geospatial layer modified by Fitzgerald et al. 2013.
- BOPRC’s ‘WetlandVegetationType’ geospatial layer.

- Protected Natural Area Programme (PNA) and Significant Natural Area reports (e.g. Wildlands 1996).

These sources provide (or could potentially provide) information on:

- Significance levels and WONI rankings.
- Current and historic wetland extent by wetland type.
- Diversity and extent of vegetation types.
- GIS based Ecological Integrity Index.

12.3.1 Significance levels (under BOPRC RPS criteria 2008) and WONI rankings

Fitzgerald et al. 2013 undertook a desktop analysis of significance levels for wetlands in the Bay of Plenty region, based mainly on dated PNA surveys and DOC reports. This analysis indicates that there is insufficient information to assess the significance of most (127/132) wetlands in the Rangitāiki WMA, but that at least four could be considered nationally significant, and at least one regionally significant.

The Waters of National Importance (WONI) project ranked wetlands in the Bay of Plenty biogeographic unit (which differs from Regional Council boundary) based on complementarity, ecological integrity, and irreplaceability (refer Ausseil et al. 2008). According to this ranking, the Rangitāiki WMA contains the top three most significant wetlands in the Bay of Plenty biogeographic unit.

12.3.2 Current and historic wetland extent

A map of New Zealand’s historic (circa 1840) wetland extent was produced by the WONI project, using soil information held by the Land Resource Inventory (Newsome et al. 2000), and a 15 m digital elevation model to refine soil polygons (Ausseil et al. 2008).

The Landcover Database (LCBD4) mapped four wetland land cover classes based on satellite imagery from 2012. However, LCDB has large errors (O’Donnell & Zanders 2006) and is not particularly effective at identifying small wetlands or wetlands within intensively farmed or peri-urban landscapes (Davis et al. 2013).

Thus the best available map of ‘current’ wetland extent is provided by the BOPRC ‘WetlandExtents’ layer, which is based primarily on 2004-2007 aerial photography with limited ground truthing. Clipping the WONI historic and BOPRC ‘WetlandExtents’ layers to the Rangitāiki WMA boundary indicates that:

- Current wetland extent in Rangitāiki WMA is only ~27% of historic extent.
- Wetlands in Rangitāiki WMA make up 24% of wetland area in the Bay of Plenty.
- Wetlands in the Rangitāiki WMA are mostly small (70% are <5 ha).

While this reduction is not severe in comparison to other catchments, and the Bay of Plenty region generally (8% remaining), it is likely to have had significant effects on wetland species diversity and condition.

12.3.3 Wetland type extent

Freshwater wetlands can be classified into types (e.g. swamp, marsh, fen, bog) according to water and nutrient regimes and substrate characteristics. Because different wetland types harbour distinctly different species assemblages (Johnson & Gerbeaux 2004), maintaining the full range of wetland species in the Rangitāiki WMA requires the maintenance of the full range of wetland types.

Wetlands in the WONI historic extent map are classified by wetland type based on soil attribute data and a 15 m digital elevation model (Ausseil et al. 2008). Additionally, wetlands in BOPRC's 'WetlandExtents' layer have been classified by wetland type based on vegetation information in BOPRCs 'WetlandVegetationType' layer, aerial imagery (RDAM 2010), Protected Natural Area reports, and individual wetland surveys (refer Fitzgerald et al. 2013).

Clipping the historic WONI and modified BOPRC 'WetlandExtents' layers to the Rangitāiki WMA boundary indicates that wetlands in the WMA fall into four main wetland types: fen (23%), swamp (60%), marsh (14%) and shallow water (2%) (noting that both mapping exercises will have missed many small wetlands, including seepages, due to limited resolution of satellite imagery and aerial photography).

The current and historic areal extent and percent remaining for each of these wetland types is shown in (Table 29) below:

Table 29 'Current' and historic extent of wetland types in the Rangitāiki WMA.

Wetland class	Area current (ha)	Area historic (ha)	% remaining
Fen	215	556	39
Marsh	134	757	18
Shallow water	19	-	-
Swamp	562	2,676	21
TOTAL	929	3,989	23.5%

Marsh wetlands have been the most reduced in extent within the Rangitāiki WMA, but have the largest average wetland size (33 ha). Swamps make up the majority of wetlands remaining in the WMA, but have the smallest average wetland size (9 ha). Fen wetlands (the type most sensitive to nutrient and sediment inputs) have been least reduced in extent, and have an average wetland size of 30 ha.

12.3.4 Diversity and extent of vegetation types

Diversity of vegetation types within and among wetlands influences habitat heterogeneity, and thus is likely to play an important role in determining overall wetland species diversity in the Rangitāiki WMA. However, diversity of vegetation types can be impacted by invasion by exotic species and/or take over by species tolerant of excessive nutrients and altered hydrological regimes.

Some data on vegetation types within the catchment wetlands is available through PNA surveys, and surveys undertaken by BOPRC to ground truth wetlands in the 'WetlandExtents' geospatial layer, but this data is very dated (mid 1990s and ~2007 respectively), and doesn't cover all wetlands.

Data on vegetation extent and diversity from these sources has not been summarised for the purposes of this report, but could provide a useful baseline data against which to assess change in extent and diversity of vegetation types should vegetation mapping be repeated in the future.

12.3.5 Ecological Integrity Index

The Ecological Integrity (EI) Index in the Freshwater Environments of New Zealand (FENZ) national database was developed for individual wetlands as part of the WONI project based on GIS based measures for naturalness of catchment cover, artificial impervious cover, nutrient enrichment, introduced fish, woody weeds, and drainage (refer Ausseil et al. 2008 for more detail).

Recent analyses by Clarkson et al. 2015 found that the EI Index is a good predictor of the field assessed ‘Wetland Condition Index’ (WCI) (refer Clarkson et al. 2004 and Clarkson et al. 2014). This indicates that the EI Index can probably be used in cases where WCI scores for individual wetlands are not available (as is currently the case for wetland in the Rangitāiki WMA).

The EI Index is expressed as a value between 0 and 1, with higher values predicting more pristine condition and lower values indicating degradation. The EI index predicts that many wetlands in Rangitāiki WMA are likely to be degraded, as 90% of the WMAs wetlands have an EI Index of 0.3 or less, and the average EI Index is 0.3.

Frequency of EI scores in the Rangitāiki WMA are shown in Figure 1 below, while average EI scores for the different wetland types in the Rangitāiki WMA are provided in (Table 30) below. EI Index scores for wetland types suggest than fen wetlands are likely to be in better condition than swamp and marsh wetlands, though this may not be true given fen wetlands are typically sensitive to sediment and nutrient inputs.

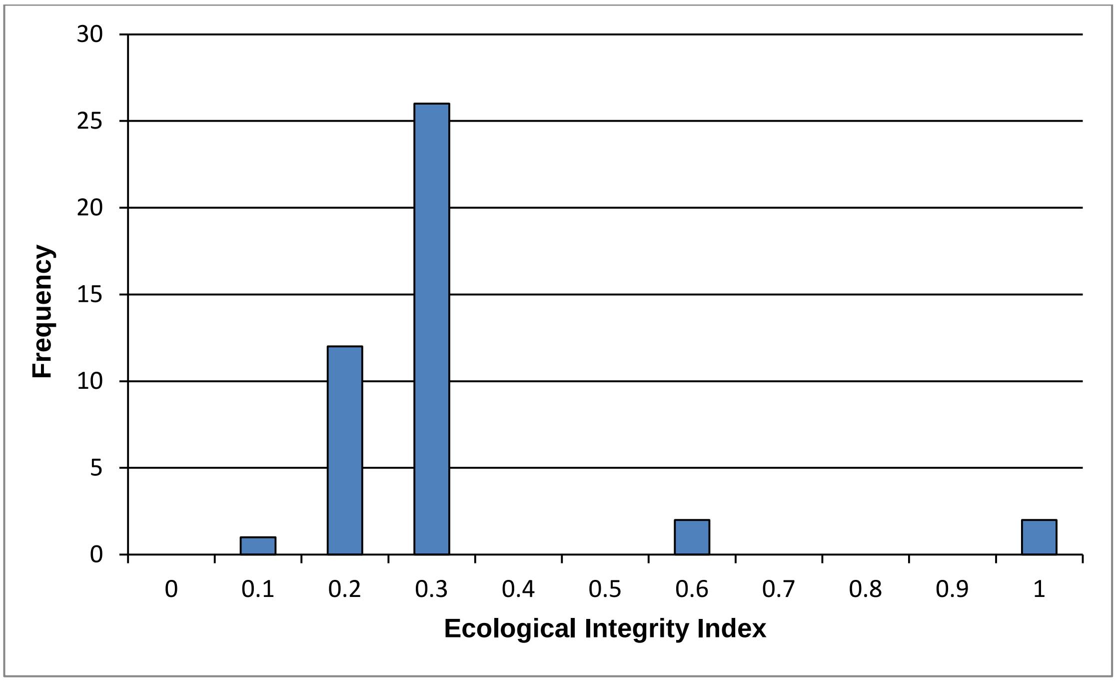


Figure 15 Histogram of the Ecological Integrity Index for 44 wetlands in Rangitāiki WMA.

Table 30 Average Ecological Integrity Index for wetland types in the Rangitāiki WMA. Wetlands types with low EI Index are likely to be subject to greater levels of human disturbance than wetland types with higher scores.

Wetland type	# WONI sites	Average Ecological Integrity
Fen	5	0.43
Marsh	1	0.26
Swamp	35	0.32
Shallow water	2	0.78

12.3.6 Rankings for naturalness, viability, and diversity

Various reports (including those undertaken for the Protected Natural Area Programme) have assessed sites in the region against Bay of Plenty Regional Policy Statement Heritage Criteria and have thus given sites a score of high, medium or low for Naturalness and Viability criteria. No attempt has been made to assess the extent to which these reports cover wetlands in the Rangitāiki WMA or to summarise the scores given to wetlands in the WMA.

12.4 Gaps and recommendations

Data on the health of wetlands in the Rangitāiki WMA are currently limited and dated. More specific data may be available from other agencies for individual wetlands but this is not currently in an easily digestible format. Key knowledge gaps, and recommendations for addressing these gaps, have been listed in (Table 31). Note that improved direction regarding monitoring required to meet the needs of NPS implementation will be possible following development of wetland NOF attributes.

Table 31 Recommended solutions to address gaps in current knowledge.

Gap theme	Gap	Recommendation
Improvements to methods and reporting	Lack of NOF attributes for wetlands.	Collaborate with other Regional Councils to support development of NOF attributes for wetlands. Better direction of additional monitoring required to meet the needs of NPS implementation will be possible once attributes (and values) have been fully developed.
Identify values	Values for wetlands.	Following availability of NOF attributes for wetlands, establish agreed values for wetlands in collaboration with communities. This will enable better direction of additional monitoring to meet the needs of NPS implementation.
Obtain new data Improvements to methods and reporting	Lack of up to date/comprehensive geospatial layers for wetland size and areal extent.	Update the geospatial layer for wetland extent using the latest aerial photography (and other available tools), and use new geospatial layer to determine changes in wetland extent, extent of wetland types, and size of wetlands over time.

Gap theme	**Gap**	**Recommendation**
Obtain new data	Lack of quantitative plot based data on plant species composition and biomass paired with sampling of soil and foliage physico-chemistry.	Undertake NERMN regional wetland monitoring programme within the WMA as planned but consider increasing sample size for the WMA to provide better catchment level data.
Obtain new data/identify values	Lack of field verified classification of sites by wetland type.	Undertake field verification of wetlands types based on soil/water chemistry and hydrology etc and incorporate into attribute table in geospatial layer of wetland extent.
Obtain new data	Lack of up to date geospatial layers for wetland vegetation types.	Undertake vegetation type mapping for mapped wetlands and consider assessing changes in extent and diversity of vegetation types compared to PNA and other survey reports.
Obtain new data	Lack of data on wetland condition/ecosystem health.	Undertake field based assessment of Wetland Condition Index for mapped wetlands or update Ecological Integrity Index (or other GIS based assessment) for all mapped wetlands using updated/recent GIS data.
Obtain new data	Lack of data on wetland condition and threats for highly significant, irreplaceable and/or vulnerable wetlands.	Undertake comprehensive monitoring of wetland condition ecology, water quality and/or hydrology) for selected highly significant, irreplaceable and/or vulnerable wetlands.
Data for models	Lack of models for to supporting decision making and estimation of cumulative impact on wetlands.	Investigate opportunities for model development (or supporting model development), in particular models to estimate phosphorus risk for wetlands.
Improvements to methods and reporting	Lack of interpretative data for determining cause of declines in wetland condition.	Manage information on land management activities (i.e. fencing of waterways, farm/nutrient management plans) in a way that will allow this information to be used for interpretation of wetland condition data.
Obtain new data	Lack of data on changes wetland condition/ecosystem health over time.	Consider analysis of Fish and Game Council data on waterfowl survival/production as an indicator of long-term trends in wetland ecosystem health.

Part 13: Other considerations

13.1 Introduction

While this review shows that BOPRC monitors a wide range of parameters in the Rangitāiki WMA, it is apparent that there are many gaps in the current monitoring programmes. The requirements under the NPS-FW have now placed a much greater demand on monitoring programmes than has occurred in the past. The challenge is how to best fill these gaps given resource and time constraints.

The next step is to prioritise and rank these knowledge gaps so that the needs of the NPS-FW implementation process are met. In undertaking such a ranking process, it is important to consider a number of key issues, including that:

- Monitoring needs to examine more than just the compulsory national attributes.
- Monitoring needs to be representative of the range of land uses.
- A high degree of longitudinal connectivity (links) exists between waterways and their ultimate receiving environments such as lakes or estuaries.
- There is a need for better integration of different science programmes.
- There is a need to consider the data and information needed to support computer models.

By considering these issues as part of the gap analysis and prioritisation process, it is expected that more informed decisions can be made about gaps which need to be addressed as a matter of urgency and those which can be regarded as lower priority.

13.2 Other attributes

Under the National Objectives Framework in the NPS-FW (Section CA) Council is required to identify any attributes (in addition to compulsory attributes in NPS-FW Appendix 2) that are considered appropriate for each value that Council identifies for each freshwater management unit (including compulsory national values and other values). Many of the compulsory national attributes are focused on water quality and algal biomass (as chlorophyll). These parameters are likely to be affected by changes in land use activities such as the intensification of farming and urban development.

Managing water quality in accordance with the compulsory national attributes and national bottom lines alone will not be sufficient to ensure all ecosystem health values are supported. The compulsory national attribute values for nitrate and ammonia are designed to avoid chronic or acute toxicity to aquatic life. These values may do little to avoid the potential adverse effects of nutrients on ecosystem functioning. For example, nitrate and ammonia may meet the national bottom lines and yet still result in algal blooms (although these are effects arguably covered by monthly monitoring of chlorophyll biomass).

It is important to recognise that monitoring needs to cover more than just the compulsory national attributes. Indeed, Policy CA2 of the NPS-FW specifically requires councils to identify other relevant attributes for their situation. This is important, as streams could arguably meet the current NPS bottom lines for the two compulsory standards of “human health for recreation” and “ecological health”, and yet show a marked decline in overall ecological condition. This is because other important parameters that affect ecological communities in streams, such as sediment, and habitat condition, are not included in the NOF. Sediment, in particular is a highly relevant contaminant in streams draining catchments dominated by pasture and exotic forest, and is well known to cause significant adverse ecological effects (e.g., Ryan 1991, Clapcott et al. 2011). In some cases sedimentation may also be a major contaminant in streams draining urban areas.

In-stream habitat condition such as substrate, flow, and riparian vegetation may also change dramatically as a result of land-use activities and effect ecological health. For example, increased sedimentation may make substrate conditions in streams unsuitable for many invertebrate taxa, and for many fish species that require clean gravels to spawn upon. Removal of riparian vegetation will also affect invertebrates by increasing the amount of sunlight reaching a stream, which may result in higher water temperatures, or higher algal biomass. Riparian vegetation is also important to many native fish, which spawn amongst native grasses or leaf litter during periods of high flow.

Identification and selection of an appropriate suite of attributes to support values will follow confirmation of values, later in the NPS-FW implementation process.

13.3 Land use representativeness

Monitoring frameworks should include appropriate representation of different catchment land uses so that the effects of these can be identified. Although it is important to monitor streams flowing through the most developed catchments (where the most pressure is likely to occur), it is also important to monitor the same compulsory national attributes in less modified streams where these attributes are likely to be in the A band. This is important, as it allows limits to be considered for stream types where the community wishes to maintain a high level of quality and ecological health (Policy CA2 b in NPS-FW). It also allows the results of monitoring streams draining more modified catchments to be put into perspective. Because of this, it is important to also monitor streams draining catchments dominated by exotic and native forest.

Monitoring streams flowing through exotic forest is important so that BOPRC can assess the long-term effects of forestry on stream ecosystems. This is especially important considering the potential effects on forestry activities in relation to sediment inputs (Harding et al. 2000), as well as potential effects on water yield as a result of increased interception and transpiration (Fahey and Watson 1991). Any reductions in water yield as a result of afforestation has potential implications for the setting of low flows in the lower areas of the catchments.

Monitoring streams flowing through catchments dominated by native forest is also important as it allows natural changes in water quality, ecology and flow to be documented over time in the absence of significant human activity. In this way we are able to determine whether climate could be responsible for any degradation (or improvement) identified in streams flowing through more developed catchments.

13.4 Links to receiving environments

Rivers and streams usually discharge into lakes, estuaries or harbours, or to the open coast. These receiving environments represent the ultimate destination for contaminants that are transported via rivers and streams. They often act like sinks, and contaminants can build up in them over time, often with ecological consequences.

Although the NPS-FW is primarily focussed on freshwater, Policy A1 (a) (iii) requires Council to have regard to the connections between freshwater bodies and coastal water. When considering limit setting in rivers, it is imperative that the cumulative impacts on the receiving environment are actively considered and accommodated into the freshwater management approach to be implemented under the NPS-FW.

For a number of reasons, monitoring programmes (and reporting) are generally segregated by water body (e.g. lakes, rivers, estuaries etc.). The NPS-FW identifies the need for this integrated approach to managing freshwater in whole catchments, including the interactions between freshwater ecosystems, land and the coastal environment. Within the Rangitāiki WMA, two clearly defined receiving environments are Lakes Aniwaniwa and Matahina. However, these are not natural receiving environments.

13.5 Better integration of science programmes

A wide range of scientific investigation programmes have been conducted within the Rangitāiki WMA. Traditionally, much of the science conducted by BOPRC has been focused on the individual disciplines (e.g. water quality, ecology etc.), with monitoring designed to maximise the scientific information of relevance to each. For example, there is a relatively large disassociation between water quality monitoring sites and invertebrate monitoring sites. This reflects the practicalities of monitoring river systems. Ecological monitoring is limited to 'wadeable' streams and is more concerned with investigating headwater catchments where the effects of land-use changes to ecology are more pronounced. Whereas water quality monitoring can only practically monitor a few key locations in a catchment, As such water quality monitoring sites occur in key locations which cover key catchment attributes or all of the catchment in some cases.

Many of the recommendations made in this review have highlighted the need to collect data at new sites within the Rangitāiki WMA. These recommendations have been made across most of the science disciplines. There is an opportunity to obtain better coordination between the different science programmes to ensure that BOPRC is monitoring as many parameters within a catchment as possible. It is therefore recommended that a number of "Sentinel sites" be established throughout the Rangitāiki WMA where detailed and coordinated monitoring is undertaken of groundwater, surface water (including quantity and quality), soil attributes (including nutrients), and ecology (periphyton, invertebrates and fish). These could be established at a few locations of differing land uses, so that links between land-use intensification, effects on water quality and quantity, soil attributes, and the resultant ecological responses can be unravelled over time.

It is envisioned that long-term data gleaned from the use of such Sentinel sites will allow BOPRC to both better communicate its science to the community, and to fulfil its obligations under both the RMA and the NPS-FW.

13.6 Modelling needs

One of the key challenges under the NPS-FW is for BOPRC to maintain or improve water quality in the face of a community desire to continue land-use development associated with agriculture (dairy or beef farming, horticulture, or cropping), forestry activities, and urbanisation. Many of the recommendations made in this report centre around the need to collect more data so that relationships between pressures associated with land-use development and the resultant water quality/ecology can be quantified and better understood. However, it is impractical and unrealistic to assume that BOPRC can measure everything. There is, therefore, an undeniable imperative that a large component of the NPS implementation work will involve the need to model interactions between land use activities and water quality.

Extensive use of models has two major benefits. Firstly, measurements and knowledge obtained from some locations can be applied to other locations For example, reliable estimation of nutrient losses from farmland is fundamental in understanding relationships between economic productivity from farming and any potential environmental effects associated with nutrient losses and possible associated periphyton blooms. The likelihood of such blooms is, however, driven by many factors other than just nutrients, including hydrology, substrate size, and shade. Any ecological models predicting the effects of increased nutrients on periphyton biomass will thus also need a strong hydrological component, as well as the ability to model predicted substrate size and shade.

The second benefit of a strong modelling component is that models allow “what if” assessments of future scenarios to be made: i.e. they are predictive tools. This is a highly important attribute, as it will allow BOPRC staff the ability to model different land use scenarios and how these may affect defined management objectives, and instream values. Such scenario testing is envisioned to be an important part of any community consultation to show the community what potential effects are of different development scenarios.

Other important interactions to consider is the need to understand linkages between surface and groundwater, as streams which are predominantly surface water fed are likely to respond very differently to the effects of land use intensification than streams which are predominantly groundwater fed. In addition, groundwater resources may or may not be affected by land use activities. Thus, groundwater resources in unconfined aquifers which are hydraulically linked to soil water are likely to be affected by increases in nutrients associated with land-use intensification, whereas groundwater resources in deeper, confined aquifers may not be affected to the same degree.

The importance of models showing the interaction between land use and nutrients has been highlighted by both the Land and Water Forum and MFE. This importance is also reflected in the large number of models that are currently available in New Zealand that link land use and water quality. For example, Cichota and Snow (2009) identified 17 different models used to estimate nutrient loss from pasture farms in New Zealand. These models differed greatly in their spatial and temporal resolution, and in the number of different processes each model considered. Simple models were typically associated with large spatial and temporal scales, and were used to calculate average annual losses of nutrients from a farm or catchment.

Because these models were based on large-scale processes, they were built on relatively simple systems, as the variability of many processes decreases at large spatial scales. More complex models are used at smaller spatial scales in order to better understand processes operating within, for example, a single paddock. Cichota and Snow (2009) highlight that different models are appropriate for different purposes, and so it is important to know what each model can and cannot do, and select the most appropriate model for the user's needs. Thus, models designed to accurately predict nutrient losses at small scales such as a single paddock may be of interest to researchers, whereas models designed to predict nutrient losses at the catchment scale may be more useful to organisations such as BOPRC for their NPS implementation work.

Although Cichota and Snow identified 17 models to estimate nutrient losses, it must be emphasised that understanding nutrient losses from a farm to a stream is only half the story. As discussed, any effects of nutrient enrichment on streams can be mediated by the interaction with groundwater, and so it is important to understand and model groundwater and surface water interactions throughout the catchment. It is also important to understand and model stream flow throughout the region, particularly as not all waterways in a region can be gauged. Finally, ecological models also need to consider interactions between a stream’s nutrient and flow regime, and the resultant periphyton biomass that will form. This is important as periphyton biomass is the only NOF attribute that has direct relevance to ecosystem health.

It is important to also recognise the fact that nutrient inputs are only one stressor arising as a result of land use intensification. Increased demand for water is often a consequence of land use intensification, and within the Bay of Plenty, there is a high demand for water from a wide range of agricultural sectors including dairy, cropping, and horticulture. The NPS-FW requires Council to set environmental flows and levels at the amount of water in a freshwater unit which is required to meet freshwater objectives. For this reason, more robust methods such as IFIM and RHYHABSIM are recommended to help inform decision making on environmental flows (and allocation) in waterways to protect ecological health.

This was the rationale behind the development of EFSAP (Booker et al. 2014), which uses generalised habitat suitability curves to model habitat retention for a range of fish species relative to mean annual low flow in all waterways. A central theme of EFSAP is also to estimate the reliability of supply in different waterways given a minimum flow derived on a pre-defined habitat protection level for a target fish species. Thus, as the minimum flow increases, so does the level habitat protection for the target fish. This is, however, countered by a reduction in reliability, and in the quantity of water available for out-of-stream users. Conversely, making more water available for out-of-stream users means there is a decrease in habitat availability for fish species, but an increase in reliability of supply. A key feature of EFSAP is to graphically model different outcomes that demonstrate trade-offs between minimum flow, reliability of supply, and habitat protection for different abstraction scenarios. EFSAP therefore relies on models of fish habitat at different flows, as well as models of flows throughout the region. Within the Bay of Plenty, Booker (2014) found that the TOPNET model most accurately predicted low flows throughout the region.

The effects of water abstraction are not just limited to decreasing potential habitat availability for fish and invertebrates, or decreasing recreational values such as kayaking and fishing within rivers. Reduced flows can also influence water quality in terms of increased temperature, reduce dissolved oxygen, and increases in concentrations (by reduced dilution) of potential toxicants such as nitrate and ammonia. The effects of low flows on water quality have been modelled using WAIORA (Jowett et al. 2004): a decision-support system designed to provide guidance on whether a water abstraction or discharge could have adverse impacts on environmental parameters such as dissolved oxygen, total ammonia, and water temperature. WAIORA uses measurements of stream geometry and numerical models to estimate how these parameters change with flow, and compares the predicted changes to environmental guidelines to determine if an adverse effect is likely to occur as a result of abstraction. It can also model what mitigation scenarios may ameliorate any adverse impacts.

Other stressors arising from land-use intensification include sedimentation. Sedimentation can have a huge adverse effect on the ecological values of waterways (e.g., Ryan 1991; Clapcott et al. 2011). As with nutrients, a number of models have been developed to predict sediment losses from catchments with different slopes, vegetation cover, and soil types. For example, SedNet calculates mean annual sediment budgets for regional scale river networks to identify patterns of material fluxes. It also predicts the sediment supply from surface and hillslope erosion, gully erosion and erosion from banks. This enables users to target management actions to improve water quality, and assists in planning catchment management actions by identifying major areas within catchments where sedimentation sources are likely to be high.

13.7 Use of models to implement the NPS

It is clear that a wide diversity of different models exist within New Zealand, each designed for different tasks. The challenge faced by BOPRC is to firstly decide which of the many models are appropriate, and secondly, their ability to be linked (i.e., their interoperability). As part of a study investigating model interoperability, Elliot et al. (2014) identified over 40 models dealing with nutrients, flow and groundwater. Summaries of these are available on the Framework for Interoperable Freshwater Models (FIFM) webpage: https://teamwork.niwa.co.nz/display/IFIM/Compilation+of+models+and+their+attributes

It is important to note that this inventory is still relatively limited and does not include water allocation models such as EFSAP, CHES, or water quality models such as WAIORA. We have examined the initial Elliot et al. list for models with high relevance to the planned work that BOPRC intends to do, and combined this with other models of relevance to the requirements of the NPS. A total of 16 models was consequently identified (Table 32). Note that this list is only indicative and likely to change depending on future examination and rationalisation of BOPRC’s modelling needs. Also to note is the absence of any specifically named models that describe interactions between algal biomass (a NOF attribute), and stream flow, or nutrient levels. Although statistical relationships between these parameters have been developed (Biggs 2000, Snelder et al. 2014), no stand-alone model currently exists that allows a time series representation of algal biomass at different spatial scales to be created.

Table 32 List of 16 relevant models potentially of interest to BOPRC as part of its implementation of the NPS. Some of this list comes from work by Elliot et al. (2014, see: https://teamwork.niwa.co.nz/display/IFM/Compilation+of+models+and+their+attributes), whilst other models were listed through consultation with BOPRC staff.

Number	Model	Description	Addresses	Purpose
1	ARC HydroGroundwater (ARC_HG)	A geodatabase design for representing multidimensional groundwater data including data from aquifer maps and well databases, data from geologic maps, 3D representations of borehole and hydrostratigraphy, temporal information, and data from simulation models.	Groundwater	Uses the ARC-GIS platform to archive, manage, and visualise groundwater information, and to create water level, water quality and flow direction maps, create, archive and visualize MODFLOW models, and create and visualize both 2D and 3D geologic models.
2	CLUES	CLUES is a catchment model developed to address implications of land use scenarios on stream water quality and some socio-economic indicators.	N and P yields	CLUES predicts the impacts of land use changes on river quality and socio-economic indicators, e.g. GDP, or employment. It also identifies sensitive and at risk catchments, such as those sensitive to the effects of dairy land use.
3	CHES (Cumulative Hydrological Effects Simulator)	Estimates the net changes to the flow regime throughout a catchment due to multiple water use schemes. It also quantifies the consequences for both the overall availability and reliability of the water resource and the residual flows that determine the in-stream environmental effects.	Hydrology - effects of allocation	CHES predicts how water flows in a catchment will change with multiple water uses (e.g. direct abstractions or storage reservoirs) and what the consequences will be to in-stream ecosystems and reliability of water-take.
4	EFSAP (Environmental Flow Simulation Allocation Platform)	Estimates how physical habitat for fish and the reliability of water supplies for out of channel users changes when different limits on water allocation are set.	Hydrology - effects of allocation	To describe the consequences of water resource planning scenarios (i.e., different options for managing water resources) on in stream and out of channel values across all parts of a catchment or region.

Number	Model	Description	Addresses	Purpose
5	FEFLOW	A professional software package for modelling fluid flow and multi-species reactive contaminants and heat transport in the vadose and groundwater zones	Groundwater	FEFLOW is a general purpose groundwater flow and transport model. It may also be linked to surface water models
6	HEM (Hillslope Erosion Model)	Estimates sediment yield and erosion from hillslopes during storm events	Sediment	
7	LeapFrog3D	3D geological modelling software	Groundwater	Allows a 3D visual representation of groundwater resources
8	Mike11	River modelling software. The core is a model for hydraulics including dynamic wave routing, but there are add-ons for rainfall-runoff (to generate inflows), contaminant dispersion, and sediment transport.	Sediment	Simulation of hydrology, hydraulics, water quality and sediment transport in rivers.
9	MODFLOW	A 3D finite-difference model for simulating saturated groundwater flow. Companion modules also track particle path lines, simulate contaminant transport, and allow simulation of chemical reactions.	Generic WQ contaminants to groundwater	A general purpose groundwater flow and transport model.
10	NZEEM (NZ Empirical Erosion Model)	Predicts mean annual soil loss from annual rainfall, type of terrain and level of woody vegetative cover. The model can be used to identify vulnerable land for soil conservation prioritisation, and to minimise erosion and flood damage. Can also be used to estimate the effects of land use cover change on erosion.	Sediment	Provides a quantitative spatial picture of where sediment in rivers is sourced and can be applied to the prioritisation of: farm plans, regional soil conservation and soil conservation for reducing sediment yield.
11	Overseer	Model for farm-scale nutrient budgeting and loss estimation.	N and P yields	Estimation of nutrient and GHG budgets for pastoral farms and arable/horticultural paddocks

Number	Model	Description	Addresses	Purpose
12	RHYHABSIM	RHYHABSIM is a habitat-hydraulic model designed to predict the amount of microhabitat available in a stream or river for fish or macroinvertebrates at different flows.	Hydrology (and Temperature)	To provide integrated solutions to common hydrometric and hydraulic computations in flow assessment, such as calculation of flow, stage/discharge rating curves, water surface profile analysis, incremental flow analysis (IFIM), including flushing flows, sediment deposition, and flow fluctuations and water temperature modelling.
13	SedNet	1. Constructs mean annual sediment budgets for regional scale river networks to identify patterns of material fluxes. 2. Assists effective targeting of catchment and river management actions at regional scales to improve water quality and riverine habitat.	Sediment	Predicts the sediment supply from surface and hillslope erosion, gully erosion and erosion from banks. This enables users to effectively target management actions to improve water quality, and assists in planning of catchment management actions by identifying the relative importance of processes supplying sediment and nutrients to the river network, and hotspot areas of each source.
14	TopNet	A semi-distributed hydrological model for simulating catchment water balance and river flow.	Hydrology	Research purposes: climate change and land use change effects on hydrological cycle. Application purposes: Simulation of catchment water balances and river flow, and flood forecasting.
15	WAIORA	WAIORA is a decision-support system designed to provide guidance on whether a water abstraction or discharge could have adverse impacts on parameters such as dissolved oxygen, ammonia, temperature and habitat for aquatic life.	Temperature, DO and habitat	Uses measurements of stream geometry and numerical models to estimate how they change with flow, and compares predicted changes to environmental guidelines to determine if adverse effects are likely occur, and what mitigation scenarios could ameliorate any adverse impacts.

Number	Model	Description	Addresses	Purpose
16	WATYIELD	Decision support tool to estimate water yield. Developed in the ICM (Integrated Catchment Modelling) project. The model is intended for use in situations where there is a limited amount of data on the climate, soils, and vegetation of the catchment, and is similar to the approach widely used for computing crop water requirements.	Hydrology	"To evaluate the effect of land use change on water yields.

One of the major challenges faced by BOPRC is to decide which of the many models as listed in Table 32 are most appropriate to help them meet their obligations under the NPS. Furthermore, many models have different inter-relationships with each other. Some models are closely linked, while others operate in relative isolation from other models (Figure 16). This raises considerable challenges to organisations such as BOPRC in deciding what models to use when trying to set limits in catchments in order to maintain specific bands for the different compulsory national attributes.

To illustrate the potential complexity by way of a hypothetical example, consultation with the community may have highlighted the fact that they wish to maintain chlorophyll biomass of a particular stream in the B-band. Chlorophyll biomass is a function of flow regime, nutrients, substrate type and shade. All of these controlling factors can be affected by land use activities. Converting a stream from plantation forestry to farming will result in large changes to the stream's hydrological regime, reflecting differences in interception and transpiration rates between plantation forests and pasture. During any conversion phase, high quantities of sediment may also be released, which may or may not affect the habitat suitability for periphyton.

Converting stream catchment land use to dairy farming is also likely to increase nutrient inputs, with potential effects on periphyton biomass. Removing a forest canopy cover and opening the stream to full sunlight is also likely to increase periphyton biomass. Finally, conversion to dairy farming may result in an increased demand for water abstraction, which would lead to low flows. These low flows may affect stream ecology through the loss of physical habitat, or may result in increased temperatures, or reduced oxygen. If BOPRC wishes to maintain algal biomass within a particular NOF band, or maintain the stream and its current ecological condition, then they are likely to have to consider setting both upper nutrient limits, as well as minimum flow requirements. Both of these questions have considerable modelling requirements, requiring models of flow, land use nutrient interactions, and any potential effects of abstraction to all be considered in an integrated way (Figure 16).

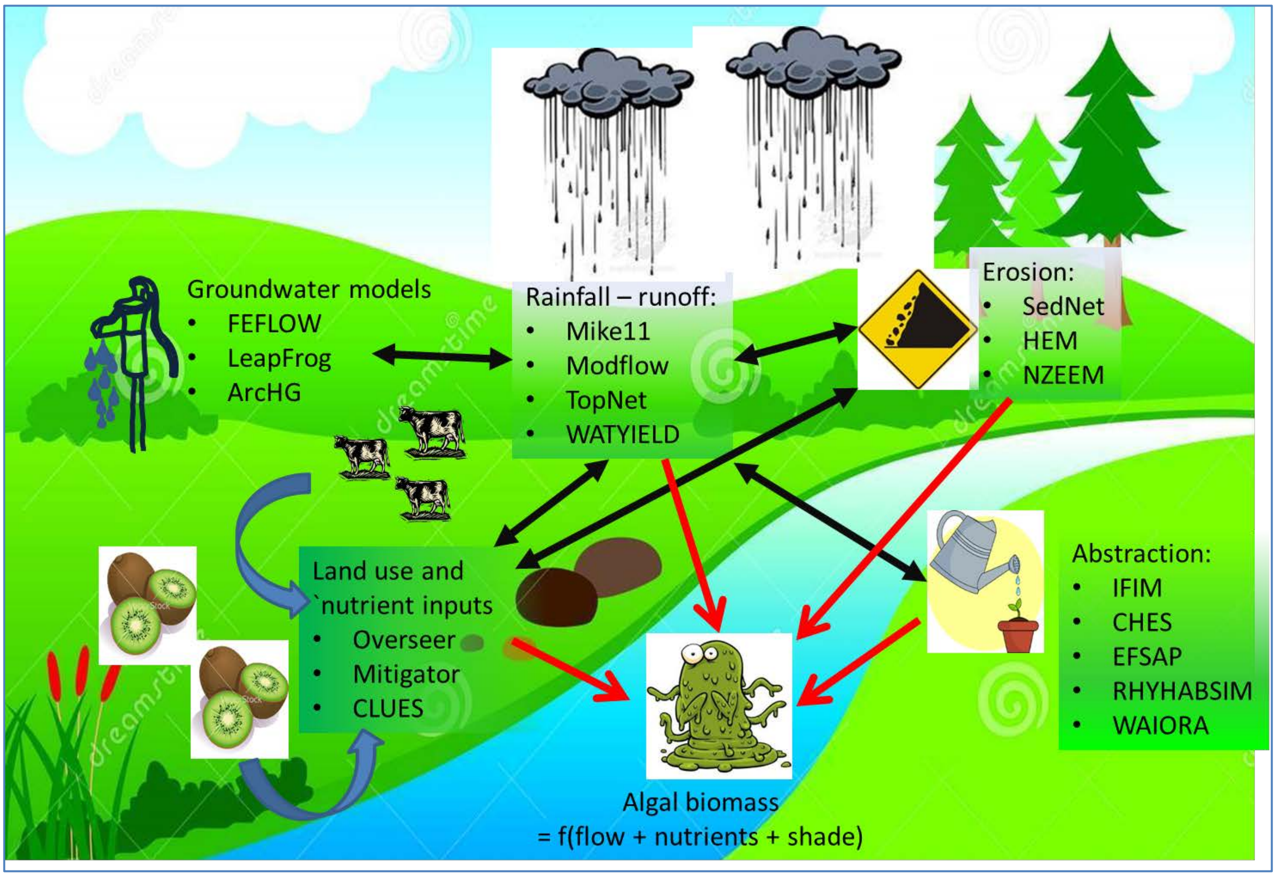


Figure 16 Schematic relationships between the different models potentially of use to BOPRC. Interactions between models are shown as black arrows. Note that in order to achieve a specific attribute (in this case algal biomass), then input from three independent models is likely to be needed (red arrows).

There is no doubt that many of these modelling requirements currently exist as stand-alone features. The real challenge exists in trying to bring these disparate models together into a more coordinated system. As part of their review of model interoperability, Elliott et al. (2014) also highlighted the fact that many end users such as BOPRC are likely to have difficulty in understanding the range of different models that are available and used within New Zealand, and how these models related to each other. To help with this, they created a new model (called ModelVis) that allows users to search for models with particular attributes, shows how a particular model may interrelate with other models, and shows where end-users can find additional information about a selected model. This is available at: https://teamwork.niwa.co.nz/display/IFM/Relationships+between+models+-+the+ModelVis+tool).

Finally, Elliott et al. investigated what software infrastructure could be used to link different models together, and made some useful recommendations as to what they considered the best platform for this task. Such platforms can be used to allow end-users to effectively link different models together rather than running them individually.

To conclude, there is a definite need for appropriate models to be used by BOPRC, but also challenges ahead in deciding which of the many models should be used. Many specific recommendations for modelling requirements have been made under the appropriate sections for each science discipline, and so a general recommendation made here would be to undertake a workshop with selected individuals to help choose and prioritise which of the many models can be used. Part of this prioritisation process should refer to the ModelVis tool developed by Elliott et al. (2014).

Part 14: Summary of recommendations

Table 33 summarises all of the recommendations presented in this report. This is an un-prioritised list of all identified gaps, large or small. Further assessment of need, urgency, and resourcing required will be carried out to determine which gaps will be filled, when and how.

The recommendations are grouped under the following themes:

(a) Spatial frameworks
(b) Obtain new data
(c) Improvements to methods and reporting
(d) Identify values
(e) Data for models
(f) Data management

For recommendations for specific science work programmes (e.g. soils, invertebrates) refer to the appropriate section of this report.

As some of the recommendations in this report are compiled from existing reports, each recommendation has been given a 'Status' to indicate whether the recommendation is 'New', 'Already Underway', or 'Planned and Resourced'.

Some recommendations (e.g. periphyton monitoring) were identified in previous reviews and have been allocated resources, others are currently being implemented. These existing recommendations have been included in this report for completeness.

The 'Status' assigned to each recommendation was used to support the process to prioritise the gaps identified. A series of meetings was subsequently held between relevant BOPRC staff to establish a priority list of work to be done as part of the gap filling process required to successfully implement the NPS-FW within the Rangitāiki WMA. All subsequent information generated as part of this gap filling process will eventually feed into work being conducted within the Rangitāiki WMA, and will be presented as a series of community workshops to highlight both the current state of the physical, chemical and ecological condition of waterways within the WMA.

Table 33 Summary of gaps and recommendations made for each Science Work Programme, arranged according to identified themes. Work which was prioritised and resourced for implementation has been highlighted (green). It is anticipated that studies in other areas will commence once the priority work has been completed.

Science work programme	**Gap**	**Recommendations**	**Status**
I. Spatial framework			
All	Under the NPS-FW, councils are expected to create their own Freshwater management units. These units need to represent streams which are similar to each other, so that appropriate limits for the compulsory national attributes can be accurately determined.	BOPRC needs to consider which spatial framework is appropriate to create water management units. These units could be based on either the REC or FWENZ classifications, or an alternative. To assist with decision-making, it may be cost-effective to get input from external experts on this matter.	New
All	Lack of spatial classification for all monitoring programmes.	Develop a consistent spatial classification for different monitoring programmes (e.g. water quality and quantity, land use and soils, and ecology).	New
Hydrology	Firm guidance as to what an appropriate spatial framework would be for stream hydrology.	Examined the appropriateness of the proposed catchment-based classification as freshwater management units for hydrology, and contrast this to other spatial frameworks that could be used for water quality and ecology.	New
Water quality	Definition of spatial scale for limit setting.	Decision be made on the scales that water quality limits will be set on. For example, with 4402 km of waterways within the Rangitāiki WMA, are the same water quality limits going to be set for every waterway within the WMA (i.e. at a WMA level)? Or are limits going to be set at sub-catchment level?	New

Science work programme	**Gap**	**Recommendations**	**Status**
Invertebrates	Freshwater Management Units need to be made at relevant spatial scales to represent streams which are similar to each other. In this way, BOPRC can accurately convey the current state of water ways in each WMA to community groups with greater clarity.	Decide on what spatial framework will be used to create freshwater management units.	New
II. Obtain new data			
Soils	When reviewing the information available from the NERMN programme it is evident that that are relatively few representative sites per WMA.	The amount of soil health information available per WMA is relatively low. It is recommended that a pilot programme is conducted to take a snap shot of soil health in the WMA. This would indicate the number of sites that are currently exceeding soil health criteria, particularly relating to fertility (nitrogen and phosphorus). The number of sites included in such a programme would need to be statistically robust enough to enable extrapolation across the WMA. If combined with land use monitoring above it will provide a powerful tool for assessing the state of the WMA. Any such monitoring programme should also include additional parameters (water quality etc) to provide a complete picture.	New

Science work programme	Gap	Recommendations	Status
Soils	Soil stability characteristics are not known within these WMAs.	Assess soil stability, soil intactness and soil disturbance over time. This analysis will help to determine whether the soil is: • stable, • unstable but inactive (erosion prone), • recently eroded, or • freshly eroded. This information will provide a framework for assessing land use disturbance due to land use. Phosphorus is a key contributor to eutrophication processes yet the loss of soil sediments to receiving waters is not well understood within the WMA. This information is critical to understanding the loss of productive soil, but also the potential for impacts on ecological values. This information could be combined with baseline soil health data to provide an indication of the state of the catchment.	New
Soils	Soil microbial/fauna populations.	Soil organic matter can play a significant role in managing nitrogen in the topsoil. This is a double benefit of allowing more nitrogen to be available to the plants while reducing the amount lost to leaching. Soil fauna populations are not well understood within this WMA and baseline information should be obtained.	New
Hydrology/groundwater	Lack of monitoring sites within geological provenances.	Target groundwater systems (aquifers) by installation of bore fields, for comprehensive monitoring and data comparison. This includes groundwater – surface water interaction.	Resourced
Hydrology	Improve calculated statistical relationships between continuously gauged and ungauged catchments.	Continue flow monitoring within catchments that do not currently have a permanent gauging station.	New
Hydrology	Lack of flow monitoring in catchments where this has been identified.	Implementing new flow monitoring sites as needed.	New

Science work programme	**Gap**	**Recommendations**	**Status**
Hydrology/groundwater	Contribution of groundwater (quality and quantity) to waterways.	Investigate the contribution of groundwater to waterways (springs, base-flow to rivers and wetlands) within the Rangitāiki WMA and the relative nutrient load contributed from groundwater sources.	New
Hydrology/groundwater	Need for improved understanding of infiltration rates to subsurface storage.	Maintain and monitor existing sites until robust statistical relations have been developed. Install new sites to obtain adequate coverage.	Additional
Hydrology/groundwater	Lack of isotope and water quality data to understand groundwater residence time (age), source and flow direction.	Isotope monitoring sites to use as a predictive tool for future water quality and quantity.	New
Hydrology	Sites that are currently over-allocated in the Rangitāiki WMA lack further hydrological analyses to set minimum flows apart from the default method.	Consider undertaking detailed IFIM surveys of sites that are heavily over-allocated, OR use EFSAP to help set more defensible low flow levels and allocation levels for over-allocated waterways.	New
Groundwater	Risk of salt water contamination to fresh groundwater resources.	Maintain and monitor existing sites to understand movement of fresh water – salt water interface with pumping stress over time. Establish new sites if necessary to address risk.	Additional
Water quality	Lack of DO profiles, especially in U-shaped streams AND Lack of DO monitoring downstream of point source discharges.	Install DO loggers downstream of point source discharges at Edgecumbe and Murupara. Loggers should remain in place from 1 November to 30 April to permit comparison against NOF bands. Support: Hamill (2012), Davies-Colley et al. (2012).	New

Science work programme	Gap	Recommendations	Status
Water quality	Under-representation of streams draining indigenous forestry and hard sedimentary geology and lowland fed streams. AND Lack of representation of tributaries draining into main stem rivers.	Initiate new water quality sampling sites (approx. 10 sites). The location of these sites should coincide with sites selected for water level/flow monitoring (see Part 9), periphyton monitoring (see Part 6), and align with sites monitored as part of ecological assessment (Suren, 2014). This could be an opportunity for sentinel sites (see Part 12). Monitor sites initially for one year and review data to determine whether relationships can be derived to long-term NERMN sites. Monitoring may need to continue beyond one year depending on the strength of relationships and the applicability of catchment models. Support: Suren (2014)	New
Water quality	Underrepresentation of dominant stream classes in the region (based on REC).	Add 10 new permanent monitoring sites to the NERMN Rivers network to better represent dominant waterways in the Bay of Plenty. Support: Hamill (2012), Donald, (2014).	Partially implemented and funded
Water quality	Impact of drainage canals.	Investigate the impact the drainage network is having on downstream water quality. NOTE: The drainage network may come under Appendix 3 of the NPS. If so, this recommendation may not be required.	New
Water quality	Connection with wetlands and wetland extent.	Re-survey wetland extent, determine connection with waterways, and incorporate WQ monitoring in wetland monitoring programme where there is a hydrologic connection. Support: Hamill (2012).	Planned and resourced
Lakes	Lake water quality monitoring in Matahina.	Conduct monthly water quality monitoring in Lake Matahina consistent with recommended protocols. Support: Suren (2014), Davies-Colley et al. (2012)	New
Lakes	Management of lake macrophytes.	Develop an action plan for Lake Aniwaniwa where excessive growth of introduced macrophytes are severely impacting on aesthetic and recreational values. AND Undertake a cost-benefit-analysis of macrophyte control options (i.e. herbicide vs harvesting).	New

Science work programme	**Gap**	**Recommendations**	**Status**
Periphyton	Knowledge is required of periphyton biomass (both spatial and temporal variability) of selected sites throughout the Rangitāiki WMA.	Periphyton biomass be monitored at selected sites throughout the Rangitāiki WMA. This supports recommendation (ii) in Suren (2015).	Planned and resourced
Periphyton	Lack of detailed information on the extent of problem *Phormidium* blooms.	As part of algal monitoring, monitor the cover of dominant algal groups, including *Phormidium*. This will provide information as to the spatial and temporal extent of any algal blooms.	Planned and resourced
Cyanobacteria	Benthic cyanobacterial cover is not a compulsory national attribute.	Given the potential danger of *Phormidium proliferations* to river users, combine *Phormidium* monitoring with routine periphyton monitoring.	New
Invertebrates	Increased knowledge is required of invertebrate communities in under-represented sites such as streams draining plantation forests.	Increase the number of monitoring sites in plantation forests as part of the NERMN programme. This has already been implemented.	New
Wetlands	Lack of field verified classification of sites by wetland type.	Undertake field verification of wetlands types based on soil/water chemistry and hydrology etc and incorporate into attribute table in geospatial layer of wetland extent.	New
Wetlands	Lack of quantitative plot based data on plant species composition and biomass paired with sampling of soil and foliage physico-chemistry.	Undertake NERMN regional wetland monitoring programme within the WMA as planned but consider increasing sample size for the WMA to provide better catchment level data.	New
Wetlands	Lack of up to date comprehensive geospatial layers for wetland size and areal aerial extent.	Update the geospatial layer for wetland extent using the latest aerial photography (and other available tools), and use new geospatial layer to determine changes in wetland extent, extent of wetland types, and size of wetlands over time.	New

Science work programme	Gap	Recommendations	Status
Wetlands	Lack of data on wetland condition/ecosystem health.	Undertake field based assessment of Wetland Condition Index for mapped wetlands or update Ecological Integrity Index (or other GIS based assessment) for all mapped wetlands using updated/recent GIS data.	New
Wetlands	Lack of data on wetland condition and threats for highly significant, irreplaceable and/or vulnerable wetlands.	Undertake comprehensive monitoring of wetland condition ecology, water quality and/or hydrology) for selected highly significant, irreplaceable and/or vulnerable wetlands.	New
Wetlands	Lack of data on changes wetland condition/ecosystem health over time.	Consider analysis of Fish and Game Council data on waterfowl survival/production as an indicator of long-term trends in wetland ecosystem health.	New
III. Improvements to methods and reporting			
Soils	No formal methodology/reporting mechanism currently exists to monitor and report on land use pressures. Intensification of land through activities such as dairying support on a predominantly dry stock block needs to be better understood/monitored.	Develop a standard methodology for monitoring and reporting on land use pressures using a range of nationally available datasets including LCDB, LUM, Stats NZ data, NERMN, Agribase etc. The reporting frequency of such reports will be limited to the availability of the underlying data and therefore a return period of less than four to five years is unlikely. Investigate combining detailed farm knowledge with land use pressure monitoring. Investigate alternative information sources such as Agribase and Statistics NZ. This information is likely to confirm how rapidly land use pressures have emerged over time and outline the current state of the WMA. Without this information it is not possible to robustly analyse how changes in land use may have impacted on ecological values within the catchment. It will also not be possible to determine the key economic drivers within the catchment and to determine what impact mitigation measures would likely have.	New
Soils	Identify NERMN soil health monitoring results for each specific WMA.	Develop a database for existing NERMN data that allows comparisons of individual sites, as well as between distinct geographic areas such as WMAs. The number of sites available in any particular area will dictate how robust the data is. A valuable data resource exists as a result of the NERMN soil health monitoring programme. The programme was designed to provide a region wide snapshot as opposed to specific soil types or catchments. See below comments on obtaining baseline information for each WMA.	Planned and resourced

Science work programme	Gap	Recommendations	Status
Soils	Dairy and kiwifruit are showing trends in soil health that need to be better understood.	The initial NERMN monitoring programme was designed around monitoring those land uses with the greatest soil disturbance. After multiple monitoring periods, it is evident that it is more appropriate to monitor the most intensive land uses more frequently and potentially reduce monitoring of those land uses that were previously more frequently monitored. It is recommended to increase the monitoring period of dairy and kiwifruit to three yearly.	Planned and resourced
Soils	The link between land use pressure, soil state and water quality is not clearly understood.	The science team should work on identifying linkages between land use pressures/soil health and water quality/ecological values. While good information exists within each discipline there have been few linkages drawn. Given that land use change can be slow to occur and any exercise linking pressure and state with Impact would be complex it would be recommended to take a long-term view on any analysis.	New
Soils	Need to monitor economic production from particular land.	This will allow us to determine the economic productivity of particular land uses and also to predict the likely impacts on the economy when making decisions about nutrients targets. Key reporting metrics would need to be decided.	New
Hydrology	Data quality analysis.	Establish confidence limits and intervals. Maintain gauging programme to ensure that establish regressions are valid. Investigate new methods, including multiple regression; regional prediction curves; and spatial interpolation. Consider synthetic stream flows.	New
Hydrology	Information on structures in surface water bodies.	Develop a GIS layer that shows the location, size of structure, water volume impounded, available minimum flow downstream, establishment of natural Q5, MALF or relevant parameter prior to establishment of structure.	New
Hydrology/groundwater	Integrated catchment management workgroup – water.	To establish a group of experts to develop and scope work programme that allows groundwater and surface water resources to be managed as a single resource, where hydraulically connected.	New

Science work programme	**Gap**	**Recommendations**	**Status**
Groundwater	Frequency and interval of monitoring to establish trends for both quality and quantity.	Standardise monitoring timeframes to provide data that can be assessed over time for trend analysis. Increase use of automated continuous monitoring sites for water level data over time. For water quality increase the frequency and establish regular sampling intervals, to allow for trend analysis over time (seasonal change).	Additional
Water quality	Monthly water quality sampling (± 1 hr) every year.	Increase the frequency of sampling at four existing sites to monthly every year. Support: Donald (2014), Hamill (2012), Davies-Colley et al. (2012)	Planned and resourced
Water quality	Flow recorded for each sampling event.	Measure flow or record stage height (to read flow of existing rating curve) on each sampling occasion for all new sampling sites established, and all current sites. Support: Donald (2014), Davies-Colley et al. (2012)	Planned and resourced
Water quality	Uncensored laboratory data.	Enter data to best estimate with appropriate coding to indicate level of accuracy. Support: Hamill (2012)	Underway (resources already allocated)
Water quality	Sample blanks and duplicates as part of QA/QC protocols.	Incorporate this process as part of standard NERMN sampling. Support: Hamill (2012)	Underway (resources already allocated)
Water quality	Consistent and regular visual clarity sampling.	Visual clarity be measured on each sampling event irrespective of stream flow. Alternate methods to be used during periods of high flow. Davies-Colley et al. (2012)	Underway (resources already allocated)
Wetlands	Lack of interpretative data for determining cause of declines in wetland condition.	Manage information on land management activities (i.e. fencing of waterways, farm/nutrient management plans) in a way that will allow this information to be used for interpretation of wetland condition data.	New

Science work programme	Gap	Recommendations	Status
Wetlands	Lack of up to date/comprehensive geospatial layers for wetland size and areal extent.	Update the geospatial layer for wetland extent using the latest aerial photography (and other available tools), and use new geospatial layer to determine changes in wetland extent, extent of wetland types, and size of wetlands over time.	New
IV. Identify values			
Soils	Cultural pressures on land are not clearly understood at this stage.	Investigate whether cultural pressures can be readily identified and incorporated into land pressures monitoring. This would involve reviewing available information sources and the robustness of any such information. It should be noted that other groups within BOPRC are investigating this work, so it is suggested as a desktop exercise to determine how readily this information could be included with other metrics.	Underway (resources already allocated)
Water quality	Values for waterways.	In collaboration with communities, establish agreed values for waterways within the WMA. This will enable better direction of additional monitoring to meet the needs of NPS implementation.	Planned and resourced
Invertebrates	Provision of any form of banding system to assign biotic metrics such as the MCI to an acceptable (A) or unacceptable (D) level.	Analysis of ecological data currently held by council, and collected as part of any future sampling could be used to help develop suggested bands for MCI scores.	New
Wetlands	Values for wetlands	Following availability of NOF attributes for wetlands, establish agreed values for wetlands in collaboration with communities. This will enable better direction of additional monitoring to meet the needs of NPS implementation.	New

Science work programme	Gap	Recommendations	Status
V. Data for models			
Soils	There is a need to identify what role pumice/gravelly soils play on nutrient loss and leaching. Overseer is used extensively to model nutrient loses, but is poorly calibrated to local conditions in the Bay of Plenty.	Conduct a detailed review on the available literature on pumice soils. Rajendram et al. have conducted a preliminary study on the impact that laboratory methods can have in overestimating Olsen P in pumice soils. Need to develop a programme to better understand the role of leaching in our most prevalent soils (pumice, allophanic and recent) and investigate utilising/leveraging off our existing lysimeter network and input into the planning for proposed lysimeters to better understand leaching in the region and these catchments. Landcare Research should be consulted to ensure any data obtained is suitable for calibrating Overseer modules. Overseer is used extensively to model predicted leaching rates and therefore, without this information, it is not possible to provide a high degree confidence in the outputs produced for certain soil types and climatic zones.	New
Soils	Do not currently have the ability to predict the effects of land change on water quality.	First phase model to allow interactive discussions on land use change scenarios and impacts on water quality with stakeholders. CLUES has been recommended as a suitable model which can be built and run in-house if desired.	New
Hydrology/groundwater	Inadequate coverage of data within geological provenances for comparison of water resource monitoring data.	Expand the geological portion of the REC to include more classes.	New
Hydrology	Proper assessment as to the accuracy of hydrological models developed by NIWA.	Compare empirically derived flow statistics against flow statistics obtained from hydrological models.	New
Hydrology/groundwater	Permitted take model.	Maintain and update existing numerical model for calculation of estimated permitted water use for inclusion to water allocation methods. Ground-truth model on five yearly cycle for WMA.	Additional
Hydrology	Groundwater flow model.	Develop and calibrate models for groundwater and surface water for the development of an integrated water resource management model.	Planned and resourced

Science work programme	Gap	Recommendations	Status
Hydrology	Surface water models for base and low flow.	Construct and calibrate model for surface water allocation.	New
Hydrology	Lack of proper validation of EFSAP model low flows.	Undertake validation of modelled habitat retention obtained through EFSAP to data obtained from a detailed IFIM surveys	New
Groundwater	Improve conceptual understanding of subsurface geology.	Designated bore fields to target depths. Record lithology and obtain cores for geological unit identification.	New
Groundwater	Lack of information on hydraulic conductance within aquifers, between unconfined, semi-confined aquifers, and also between aquifers and surface water.	Hydraulic pump testing of the aquifer systems within the Rangitāiki WMA and surface water bodies.	New
Groundwater	Conceptual groundwater model.	Maintain and update existing conceptual groundwater models from Wells database, updated DTM and geological maps.	Additional
Groundwater	Groundwater flow model.	Develop and calibrate models for groundwater and surface water for the development of an integrated water resource management model.	New
Water quality	Cumulative impact on receiving environments.	Consider the desired values in receiving environments (i.e. estuaries), establish assimilative capacity of receiving environment for the chosen variable(s), and then work upstream into the catchment to ensure limits in receiving environment can be met.	New
Water quality	Model of water quality within the Rangitāiki WMA.	Investigate opportunities for model development (or modifying existing models) to support decision making and estimation of cumulative impact on waterways.	New

Science work programme	**Gap**	**Recommendations**	**Status**
Periphyton	Linkages between periphyton, nutrients and flow.	Where possible, any periphyton monitoring should be done at sites where monthly water quality data is collected, and within continuously gauged catchments, or close to such catchments. This will allow BOPRC to: i) test current models of algal/nutrient interactions, and ii) Develop new models of interactions between algae and nutrients.	New
Wetlands	Lack of models for to supporting decision making and estimation of cumulative impact on wetlands.	Investigate opportunities for model development (or supporting model development), in particular models to estimate phosphorus risk for wetlands.	New
VI. Data management			
Soils	Include trace elements as part of the standard NERMN monitoring suite.	Trace elements are currently reported on separately from the soil health programme. They should be included in the regular NERMN monitoring and reported on in the regular soil health updates.	New
Hydrology/groundwater	Lack of regular technical reporting.	Five-yearly technical report, annual summary report, up-to-date data on BOPRC web site (or LAWA).	New
Water quality	Information from consents, compliance and land management be integrated (where applicable) with NERMN data or interpretation.	Ecological or monitoring reports for consents be registered individually in Objective (i.e. not just under consent file). Water quality data from these reports be captured in existing spreadsheets/databases (see recommendation below). Information on land management activities (i.e. fencing of waterways, farm/nutrient management plans) be grouped for each WMA and this information able to be queried/extracted as needed for purposes of interpretation of water quality data. Support: Hamill (2012)	Outstanding
Water quality	Easy access to water quality from other sources (e.g. historic sampling, data from consents etc.)	Investigate options to capture, store and maintain a portal to house all water quality data (regardless of source), with appropriate reference and quality coding.	New

Part 15: References

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